July 1959

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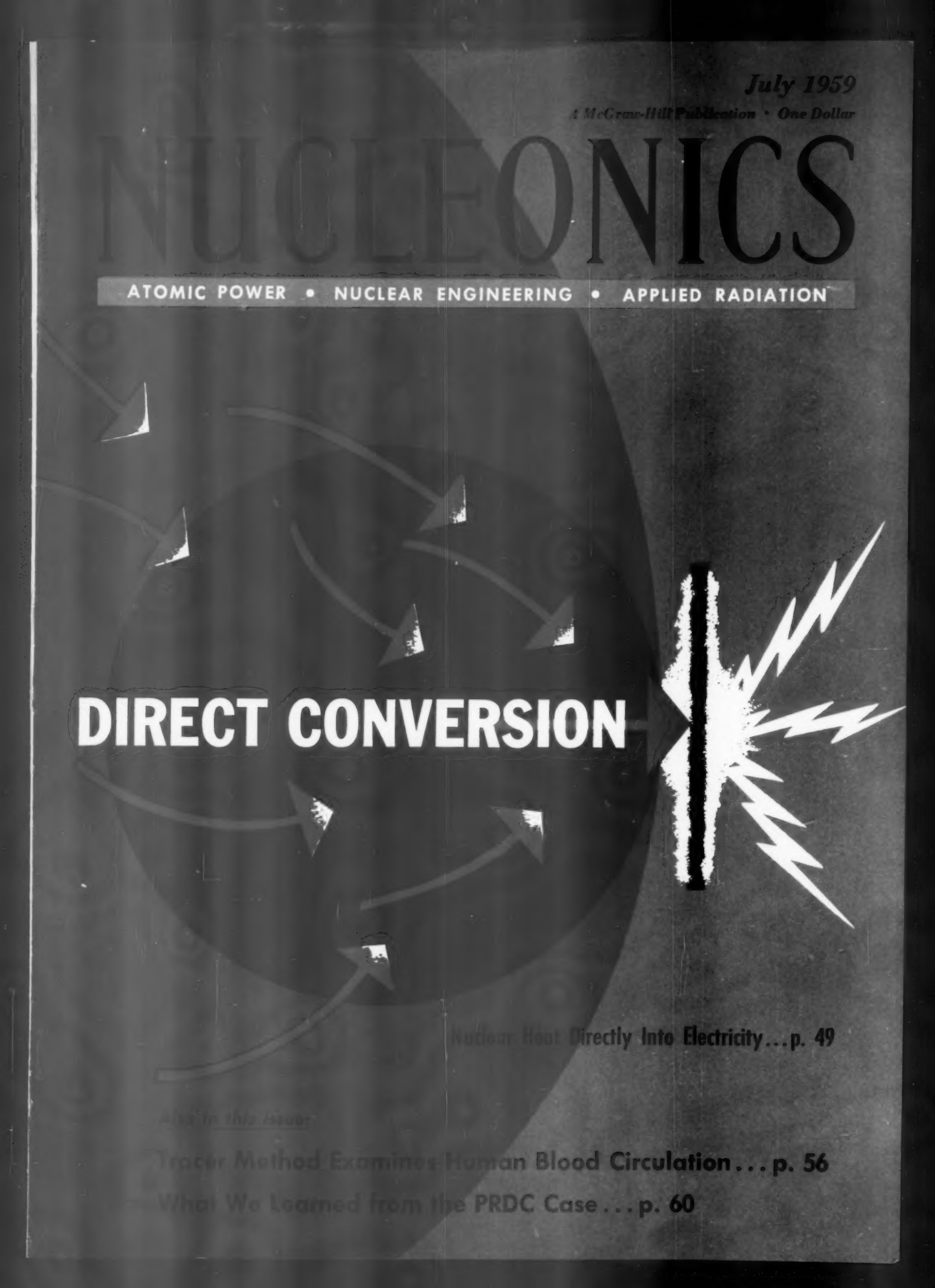
NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION



DIRECT CONVERSION

Nuclear Heat Directly Into Electricity ... p. 49

Also in this issue:

Tracer Method Examines Human Blood Circulation ... p. 56

What We Learned from the PRDC Case ... p. 60

Hamner

COUNT RATE METERS DECADE SCALERS and TIMERS

N-701C
LOGARITHMIC COUNT RATE METER

GENERAL DESCRIPTION

Designed specifically for direct counting of pulses resulting from nuclear disintegrations. There is a maximum-count limit switch that may be used to activate an alarm system or other external device, that will signal the presence of excessive radiation.

SPECIFICATIONS

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RANGES: 1) 1 - 1000 cps
2) 10 - 10,000 cps
3) 100 - 100,000 cps
4) 1 - 100,000 cps
OUTPUT: 0 − 10 mv for recorder
LINEARITY: Better than 1%
STABILITY: 1% per day (after warm-up)

N-730
LINEAR COUNT RATE METER

SPECIFICATIONS

NEW!

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High level −50 to +100 volts

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Features High Speed Print-Out For X-Ray Counting

SPECIFICATIONS

SCALE: 10^8, 10^7, or 10^8
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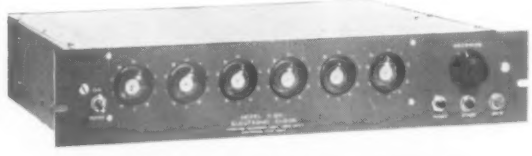
DISCRIMINATOR RANGE: High level, −50 to −100 volts
PRESET TIME, when used with N-801 Electronic Timer: From ½ second to 10,000 seconds in steps of ½ second, 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000 and 10,000 seconds
PRESET COUNT: 10, 100, 1K, 10K, 100K
1M, 10M and 100M when 8 decades are used
TEST: 60 cycle
GATING: Complete electronic gating, remote or local control



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For Use With Hamner N-270 Automatic Printer-Scaler

SPECIFICATIONS

TYPE: Glow-Tube
DRIVE: Driven from a stable 100 or 1000 cycle oscillator
PRESET TIME: From ½ second to 10,000 seconds in steps of ½ second, 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000 and 10,000 seconds
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GATING: Complete electronic gating, remote or local control.

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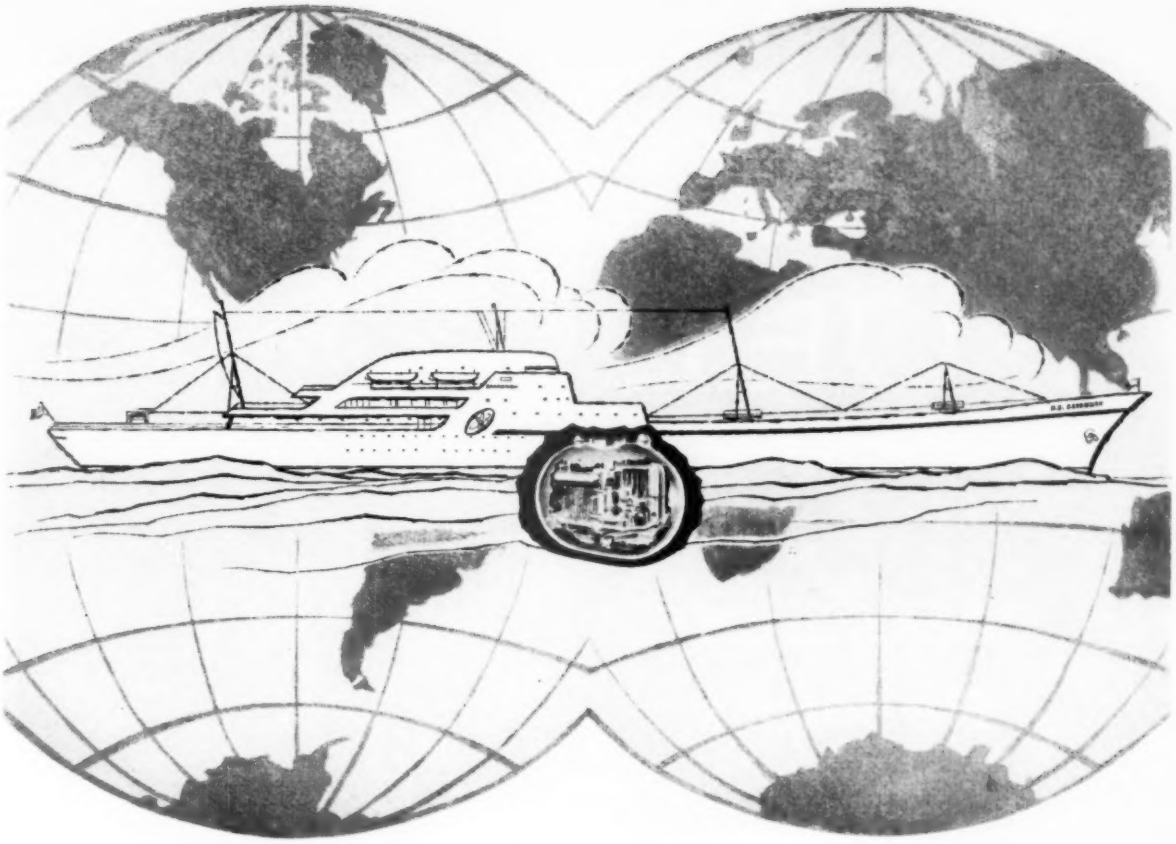

350,000 MILES ON ONE "TANK OF GAS"

The Nuclear Ship Savannah, President Eisenhower's "Peace Ship," will be launched this month. She is being built as a floating laboratory to prove the feasibility of nuclear propulsion in merchant shipping and to demonstrate to the world the determination of the United States to harness the power of the Atom for the peaceful benefit of all Mankind.

After test runs, the SAVANNAH, the world's first nuclear-powered merchant vessel, is slated to make a round-the-world tour—without refueling! In fact, she could make about 14 such tours. Her reactor is designed to operate more than three years, or approximately 350,000 miles, on ONE fuel loading.

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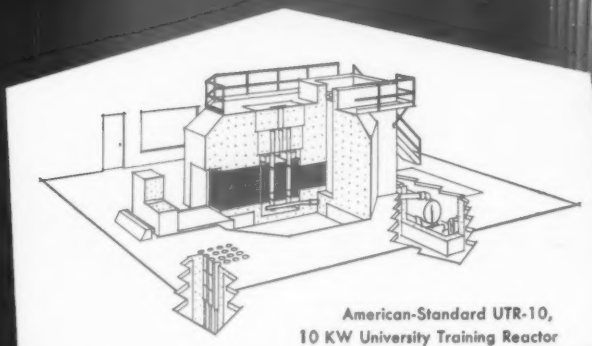

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10 KW University Training Reactor

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Fabricated at M&C Nuclear

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M&C Nuclear will be pleased to assist you in your experimental programs by supplying information on quality fuel based on your specifications and designs. Write our Manager of Marketing and Contract Administration.

The fuel plates, above, were manufactured to the following dimensions and specifications:

Weight	23 grams U^{235}
Element Length	25.938 ± .015″
Element Width	3.000 ± .015″
Element Thickness	.110 ± .006″
Fuel Thickness	.090″ nominal
Cladding Thickness	.010 ± .002″

Variations of dimensions are possible to meet special requirements.

M&C NUCLEAR, INC.

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VOLUME 17 NUMBER 7 JULY 1959

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More about NUCLEONICS on next page ▶

About NUCLEONICS

Meet Jim Thomas

We have added a new man and a new title to our staff. The man is James H. Thomas, the title is Marketing Editor. Jim (picture below) comes to us with a strong background in nuclear marketing activities. For the past three years he's been associated with Curtiss-Wright's Research Division at Quehanna, Pa. with sales, sales promotion and marketing responsibilities in connection with their training and research reactors. Prior to that Jim had received a MBA in marketing at the Wharton Graduate School of the U. of Pennsylvania. This in turn followed a stint in the Army (including a year at the Army's Language School in Monterey and a year of well-traveled service in Europe) and an undergraduate career at Hamilton College with majors in economics and biology.

JIM THOMAS, new Marketing Editor of NUCLEONICS

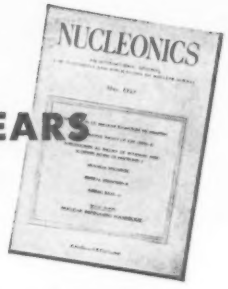
Jim's job, as we see it, will encompass many things—certainly marketing is of vital importance to the nucleonics industry and it's important that the voice of that industry have strength in the marketing area. NUCLEONICS gets many requests for information on the nuclear marketing problems—it will be Jim's job to handle these. In addition he will be responsible for programs of our own, designed to develop comprehensive statistical data on the nuclear field. Some of this material will appear in our pages as statistics and articles on the nuclear market.

Direct Conversion

Going from nuclear heat to electricity without the intervention of steam cycles and the like has long been a dream of nuclear power engineers. That dream seems a lot closer to realization now that research on thermoelectric and thermionic conversion schemes has resulted in devices with promising efficiencies. Associate Editor Hal Davis has assembled a pair of articles, one of which (p. 49) discusses the fundamentals of thermionic devices and the second of which (p. 54) describes the recent experiments at Los Alamos on their so-called plasma thermocouples. Upcoming issues will contain further news of direct-conversion schemes.

—*The Editors*

10 YEARS AGO



Classical radioactivity. In a review of the work done from 1940 to 1949 on the natural radioactivity of uranium and thorium, Professor Feather systematically lists the new values for such things as decay schemes, particles emitted, particle ranges, particle energies and half-lives. A 190-item bibliography that accompanies provides a comprehensive guide to the work in this grandfather of all nuclear research topics.—N. Feather, NUCLEONICS, July '49, p. 22.

Mesons in '49. If natural radioactivity is the grandfather of nuclear research topics, then meson physics is one of the youngest offspring. At least that is the way it was in 1949 when Conway Snyder reviewed "Current Ideas About Mesons." A tabulation of firmly identified mesons included the pi and mu only. Phenomenological identification was used for mesons labeled rho (ones that stopped without producing any observable product) and sigma (ones that produced a star at the end of their tracks). To the wonderment of workers in the field, the number of mesons and other new particles has grown enormously in the 10 years since.—Conway W. Snyder, NUCLEONICS, July '49, p. 42.

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ZIRCONIUM

costs less today than you may think!

A recently-published article in Metal Progress* provided an interesting economic appraisal of zirconium and stainless steel in nuclear power reactors. The article covered five power-producing thermal reactors spanning the entire range of fuel enrichment. To supplement these facts, we would like to add these key points about zirconium.

Check TODAY'S Zirconium prices

In our discussions with designers and builders of nuclear reactors, we still find some who think of zirconium prices in terms of $100 per pound. Actually, high quality zirconium strip and rod are available through Mallory-Sharon at *$11 to $14 per pound*. Even tubing – always more expensive in any metal–is frequently priced at under $30 per pound.

What is the break-even point?

In four of the reactors discussed in the article, the break-even price for fuel cladding material ranged from $44 to $104 per pound. On permanent parts, the range was from $109 to $842 per pound. Thus zirconium, at present prices, offers important economic advantages over stainless steel.

Future price trend important

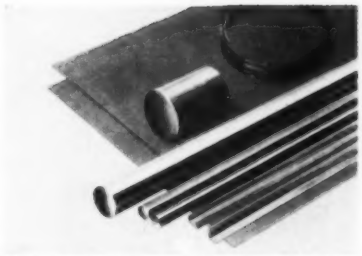
The break-even point is not necessarily a static one. Future trends in prices of both zirconium and stainless steel must be taken into account.

For example:

1. As zirconium production and use increases, price of mill products will be reduced still further.
2. Increases in stainless steel prices will raise the break-even point.

Thus, for the future, certain applications which may be borderline cases at present, will most surely show definite economic advantages for zirconium.

Careful quality control of zirconium tubing and other mill shapes is a continuous top-priority assignment at Mallory-Sharon.



Typical mill shapes produced in zirconium by Mallory-Sharon include rounds, bars, billets, wire, sheet, strip, plate, tubing.

Advantages of Zr for refueling

The declining price trend of zirconium has a vital bearing on cost of future refueling operations. Even where zirconium's present economic advantage may be close to the borderline, future price reductions will substantially increase this advantage 1½ to 2 years from now.

Use of natural uranium a key factor

Because of zirconium's low neutron-absorbing cross-section, uranium of lower enrichment may be employed. This further adds to zirconium's economic advantages through resulting savings in fuel costs.

For pricing assistance . . .

on zirconium for either fuel cladding or permanent parts, call on Mallory-Sharon. As the only integrated producer of zirconium, we are in a position to render valuable help on pricing your designs or bill of materials–as well as providing lowest prices and highest quality for all types of zirconium mill shapes.

*"An Economic Appraisal of Stainless Steel and Zirconium in Nuclear Power Reactors," appearing in Metal Progress, February, 1959. WRITE MALLORY-SHARON for free reprint!

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NUCLEAR REACTIONS

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DEAR SIR:

The May 1959 issue of NUCLEONICS Roundup section (page 30) carried an article entitled "Alco: Still Amortizing R&D but Profits Begin to Flow." In this "feature article" you indicated that the PM-1 reactor project is the new title for the APPR-1 built by Alco. This is not correct. As pointed out in your "Reactor News" section in the March issue of NUCLEONICS (page 25) the Martin Company is building the PM-1 (Portable Medium Power Reactor No. 1) under contract with the AEC for installation at an Air Force site located near Sundance, Wyo. Your even more previous article on the Army Reactor Program of the February, 1959, issue (page 54) did give the correct new designation for the Alco-built APPR-1, which is SM-1 (Stationary Medium Power Reactor No. 1). By the designations you published in your February issue I believe you will find that your names for the Army's plant at Ft. Greely, Alaska, and what you refer to as the PM-1b and SM-1 plants are also incorrect.

—F. HITTMAN
Project Manager, PM-1 Project
Nuclear Division
Martin Company
Baltimore 3, Md.

EDITOR'S NOTE: Reader Hittman is right; NUCLEONICS got bogged down in the alphabet-soup. To set the matter straight here is a table for ready reference:

Designation

Old	*New*	*Location*	*Reactor builder*
APPR-1	SM-1	Ft. Belvoir, Va.	Alco
APPR-1a	SM-1a	Ft. Greely, Alaska	Kiewit (Alco)
ALPR	SL-1	NRTS, Idaho	Argonne
—	PM-1	Sundance, Wyo.	Martin
—	PM-2a	Greenland	Alco
APPR-1b	SM-2	Nike-Zeus stations	Alco (development)

ALPR Comments

DEAR SIR:

Various members of the ALPR group at Lemont, Ill., have reviewed the article on the ALPR appearing in the February, 1959, issue of NUCLEONICS (p. 55). I am writing this letter to summarize the comments of the group.

Some of the data listed are closely associated with rather specific reactor conditions not easily presentable in tabular form. For example, under "Nuclear Design Data," a reactivity allowance of 3% is indicated for fuel burnup. Actually, the value of ~3% is the excess reactivity available in the fresh reactor operating at 3 Mw, with "equilibrium" concentrations of Xe^{135} and Sm^{149}. Additional reactivity for burnup (~12%) is stored in the burnable poison strips. Most of this reactivity is made available to the reactor as the burnable poison is consumed during operation.

Also, the range of values ($4–8 \times 10^{-5}$ sec) quoted for the mean prompt neutron lifetime applies to the entire range of core temperature and burnup conditions. In the fresh reactor, operating at 3 Mw, this value is $\sim 6 \times 10^{-5}$ sec.

Several corrections should be noted. Under "Nuclear Design Data," the subheading "Moderator" should include only the line "type—light water." The other items contained under this subheading are actually characteristics of the core or of the reflected reactor and not of the moderator alone. The "over-all temperature coefficient" is not far from 5×10^{-3}%/° F, if one defines this to be the average net reactivity loss to be compensated by partial withdrawal of control rods as the reactor water temperature is raised from room temperature to 420° F (a total net reactivity loss of ~1.5%).

Recently, costs of the ALPR have been reestimated as follows:

Estimated Cost	
R&D	$ 750,000
Power plant	825,000
Reactor plant	400,000
Site improvement	500,000
Estimated Total Cost	$2,475,000

Also, under the heading "Characteristics of ALPR," it would be preferable to substitute the value "200 kw plus 60 kw occasional overload" as the *net* electrical output. In addition, ~100 kw(e) are required for operation of the plant when the reactor core is producing 3,000 kw(th).

Under "Description of ALPR," the second-to-last paragraph before "Pressure Vessel" indicates three-year operation with a single fuel loading. This

statement should be qualified as follows:

The expectation of a three-year life of the core is based upon the result of a theoretical analysis of the net reactivity effects of consumption of U^{235} and of the burnable poison during reactor operation. The cladding thickness of the fuel is believed to be sufficient for protection of the fuel meat against corrosion during three years of operation. However, in the final analysis, the life of the core can be established only after a sufficient operating history of the reactor.

It is suggested that the Hazard Summary Report on the Argonne Low Power Reactor (ALPR), ANL-5744, be consulted for more details. This report can be purchased from the Office of Technical Services, U. S. Department of Commerce, Washington, D. C. ($2.50).

—D. H. SHAFTMAN
Reactor Engineering
Argonne National Laboratory
Lemont, Ill.

"Absolute" = Cambridge

DEAR SIR:

In an article by Sinizer, Mattern, Foltz and Kendall (NU, Jan. '59, p. 50), reference is made to "Absolute filters." We would appreciate your bringing to the attention of your readers that "absolute" is the registered trademark of Cambridge Filter Corp. For years our trademark "Absolute" has been synonymous with Cambridge and the best in air filtration as supplied by Cambridge in respect to efficiency, construction and reliability. We, therefore, feel that you can appreciate our desire to do everything possible to avoid confusion in the field of nucleonics and to see to it that the trademark "Absolute" applies only to filters of our manufacture.

—ROBERT H. AVERY
Cambridge Filter Corp.
Syracuse, New York

Correction

DEAR SIR:

The caption under Fig. 2 in our article "Paramagnetic Resonance Shows Radiation Effects" (NU, Jan. '59, p. 66), showing the paramagnetic spectrum of irradiated aminoisobutyric acid, should have indicated a splitting of 140 gauss, not 110 gauss.

—H. C. BOX and H. G. FREUND
Roswell Park Memorial Institute
Buffalo, New York

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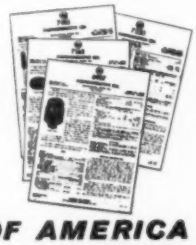

For technical bulletins covering RCA Photoconductive Cells and Photojunction Cells, write RCA Commercial Engineering, Section G-31-U, Harrison, N. J.

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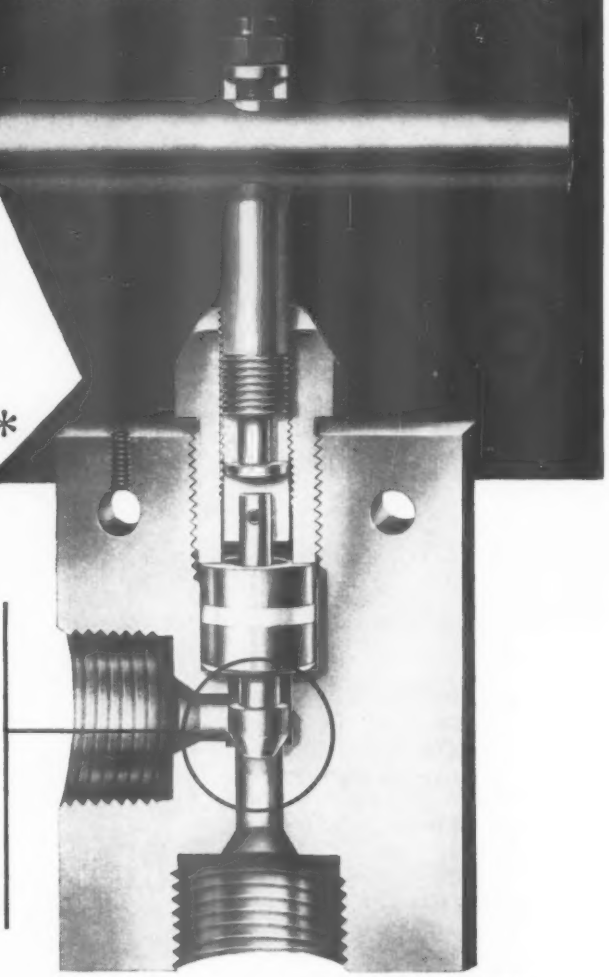

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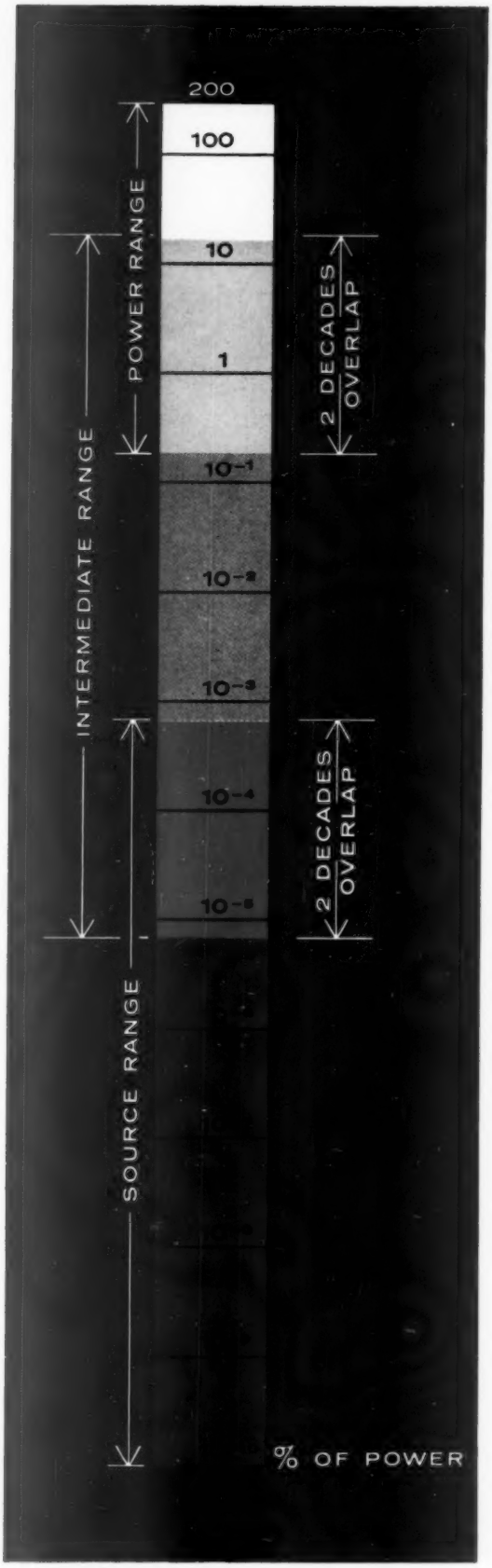

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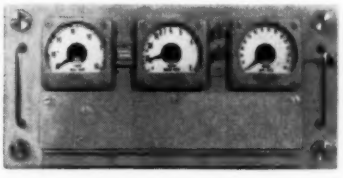

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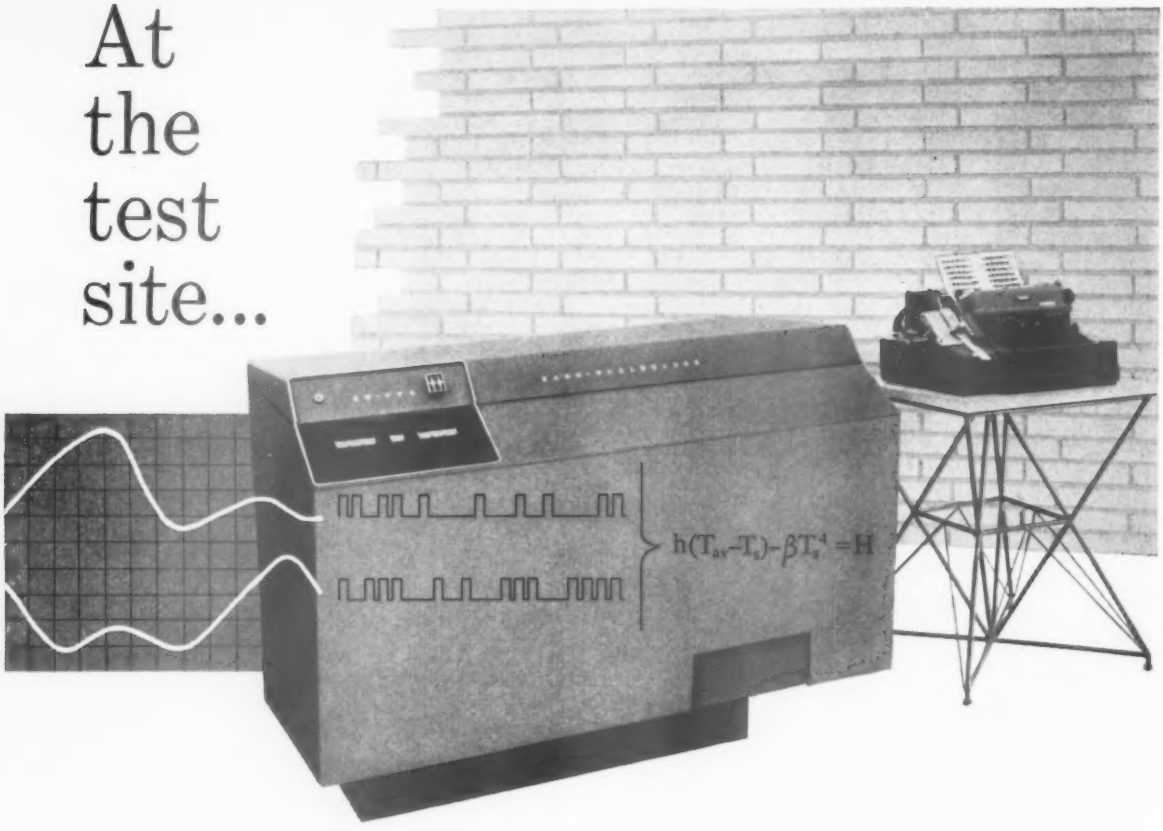

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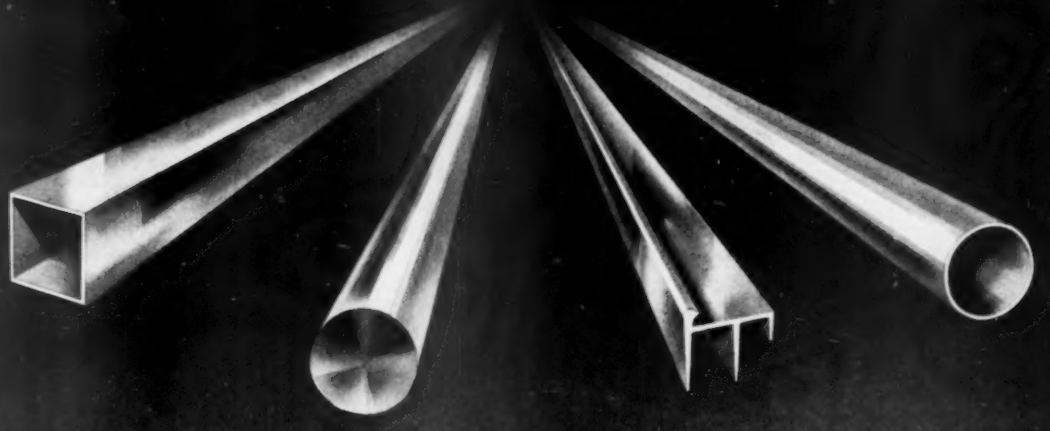

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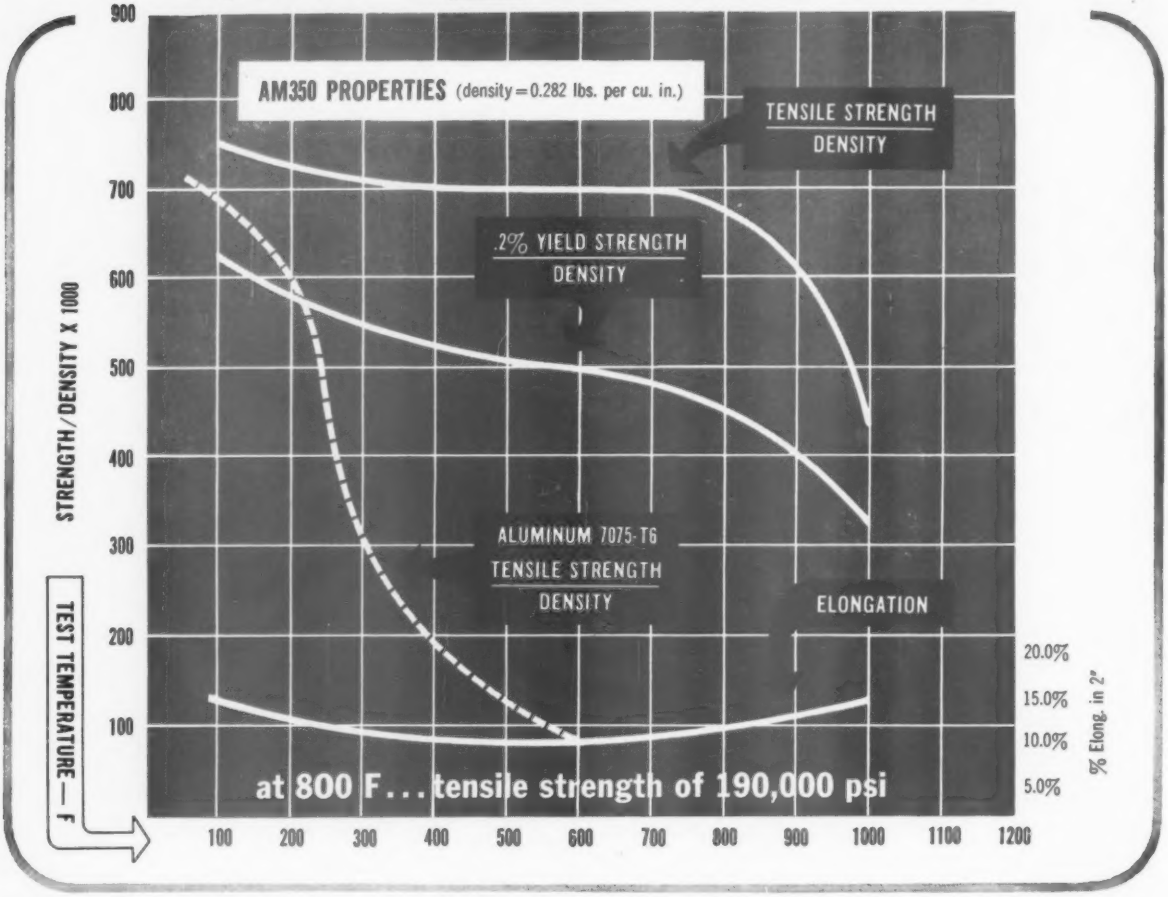

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For further information, see your A-L sales engineer or write for the booklet "Engineering Properties, AM350 and AM355." ***Allegheny Ludlum Steel Corporation, Oliver Building, Pittsburgh 22, Pa.*** Address Dept. NC-19.

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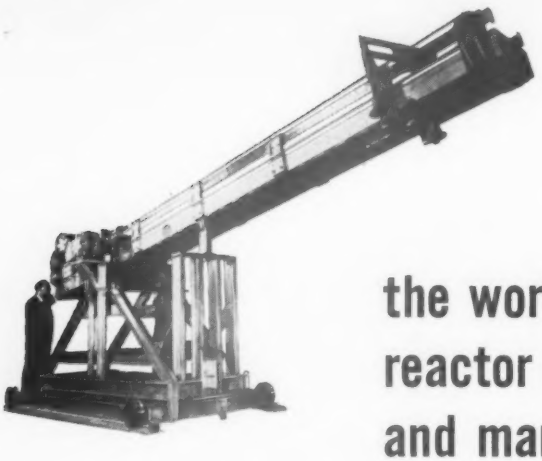
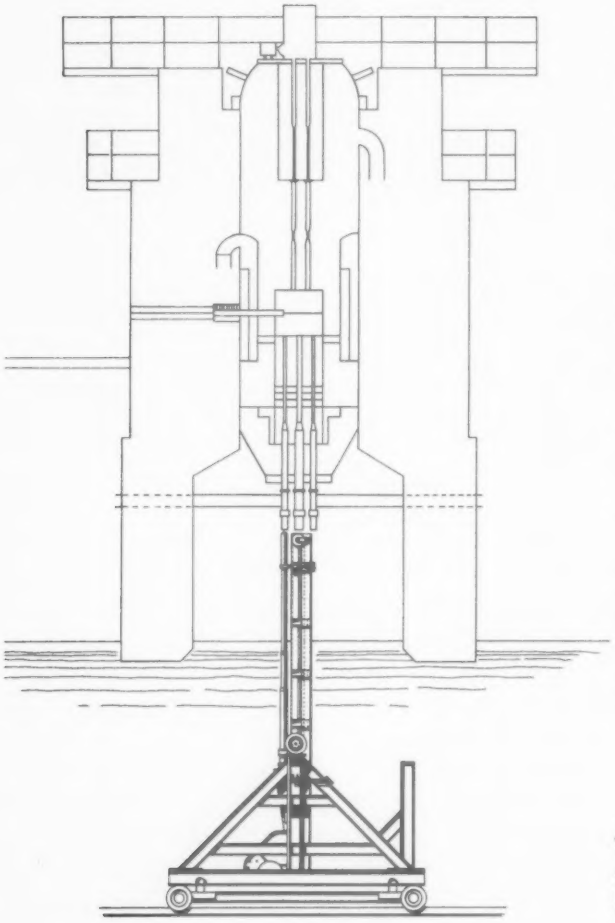


Built specifically for the new Westinghouse Testing Reactor

the world's first remotely controlled reactor thimble loader — engineered and manufactured by General Mills



Drawing shows the machine in position to insert thimble through bottom of reactor vessel.

This hydraulic Thimble Loader is another example of General Mills' know-how in the nuclear equipment field. Designed for operation under water, it plays a vital role in Westinghouse's advanced testing reactor at Waltz Mill, Pennsylvania.

Material samples for irradiation are inserted into and extracted from the core of the reactor by the remotely controlled Thimble Loader. In addition, it transports the thimbles to the hot cells entirely under water—the water acting as a shield, lubricant, hydraulic fluid, and viewing medium. The Thimble Loader is quickly and accurately positioned. Constructed entirely of aluminum, stainless steel, and bronze, it is powerful, yet precise and requires practically no maintenance.

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Just completed—the Westinghouse Testing Reactor in Waltz Mill, Pennsylvania—another example of technological progress. Congratulations Westinghouse!

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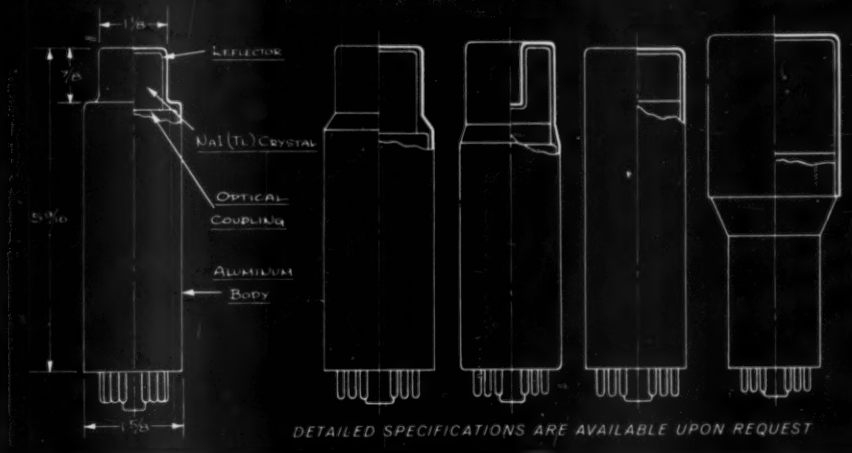

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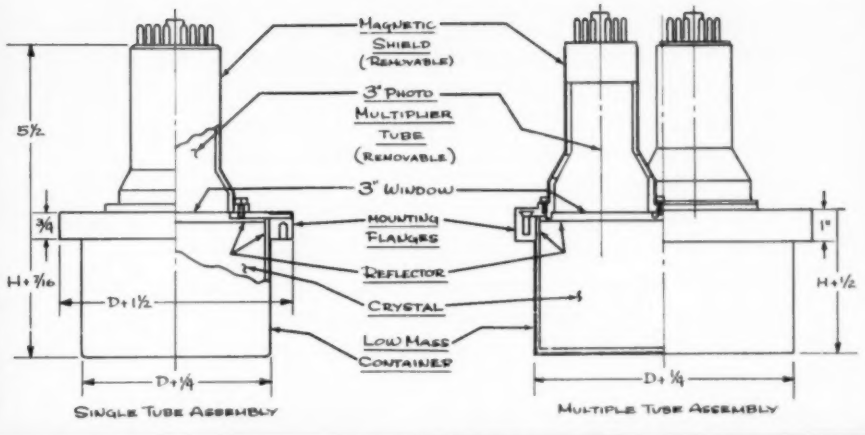

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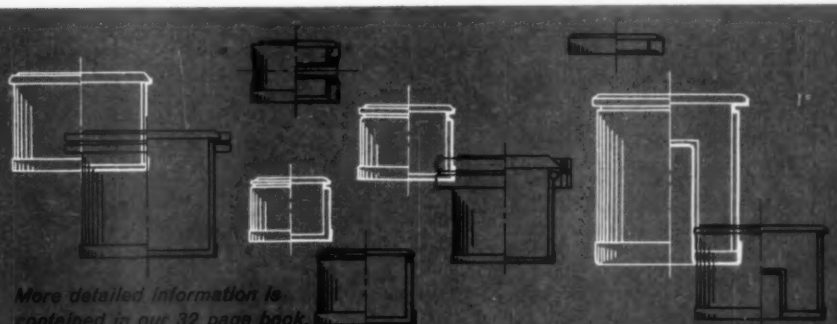

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ROUNDUP of Key Developments in Nucleonics

AEC Drafting Master Blueprint for 1960–70 Reactors

AEC's reactor planners embarked last month on a major program to draw up a blueprint for a comprehensive, ten-year civilian power reactor program. Target date for completion of the entire report is "early January" 1960.

The Commission has set up a special task force within the civilian power evaluation and planning branch of the Reactor Development division to draw up this program. It consists of half a dozen men headed by Harold Vann of the water reactors group, with industry and national laboratory experts to be used as consultants as needed.

This first attempt to organize AEC's specific reactor evaluations into a long-range integrated program is something the Joint Committee on Atomic Energy and other groups such as the Tammaro-Smyth Ad Hoc committee (NU, Feb. '59, 19) have been urging on AEC for years, and that the AEC under its previous leadership had been steadfastly balking at doing. The work is to be continuing in nature rather than ad hoc, and the program developed in the initial report will be subject to continual improvement and modification as result of further review and technological advances —just as was the 1954 five-year program, to which this will be the successor.

The scope of the study is extensive. It will include such areas as: determination of specific objectives for an over-all AEC civilan power reactor program; establishment of specific technical objectives and a chronological development program for each reactor concept; evaluation of the economic potential of each reactor type; clarification and delineation of the program to encourage development of promising new concepts and reactor types, as well as major modifications of existing concepts; and establishment of yardsticks for measuring the rate and degree of development on each reactor type.

Reactor Status Reports

As the first step toward carrying out this ambitious scheme, AEC has engaged eight top experts to draw up for it reports on the economic and technological status of as many reactor concepts. They are: William Shoupp, Westinghouse, pressurized water; John West, Combustion Engineering, boiling water; Beecher Briggs, Oak Ridge National Laboratory, thermal breeder; William Parkins, Atomics International, organic moderated; Robert Dickinson, Atomics International, sodium graphite; Robert Charpie, gas cooled; Alfred Amorosi, Power Reactor Development Associates, fast breeder; Dale Babcock, DuPont, natural uranium–heavy water.

These reports, which were assigned early in June to be turned in to AEC by end of June (in fact the reason AEC did not write them internally is that it lacked manpower to do them in three weeks) are not to be "selling jobs." AEC brought the experts in to Washington for briefing, told them what level of optimism to assume, instructed them to write a factual history of each concept showing where we stand today economically and technologically —what costs are, what technical problems loom. It is the Vann group that will then assess the potential of each concept and lay out a development program for it.

A first report is due by September, the month when the annual budget cycle begins. Thus AEC hopes that the study's recommendations for at least the first of the ten years will be reflected in the fiscal '61 budget. A final report will be filed in January.

Compromise Reactor Program Approved by JCAE; Capital Subsidy Shelved for Year of Further Study

In a long-absent spirit of compromise, AEC's $165.4-million construction authorization bill for fiscal '60 was voted out of the Joint Committee on Atomic Energy last month and sent to the House and Senate where it was okayed "as is," on June 15. Actual money for the program must be approved separately by Congress. The nine civilian, two military and one research reactors scheduled for fiscal '60 construction starts (*see chart*) represent more than AEC had asked for but less than some JCAE Democrats had demanded.

The one long-range feature of AEC's proposed program—a capital subsidy for civilian power reactors (NU, March '59, 28)—was passed over until next year because, in the words of one JCAE member, "a capital-subsidy program is not an easy thing to work out." Both AEC Chairman John A. McCone and JCAE Chairman Clinton P. Anderson (D-N. M.) supported capital subsidies in closed-door talks leading up to the JCAE vote on the authorization bill but it was finally decided that the proposal was too complicated and needed further study.

Chief architects of the '60 program were Anderson and McCone. This was particularly significant for two reasons: (1) it has ended the era of personal animosity between AEC and JCAE leaders which had hung over the U. S. reactor program for the past 4½ years; and (2) it has guaranteed that McCone will have at least a year of quiet in which to proceed with his prototype-oriented approach to economic nuclear power (NU, June '59, 22).

'Pipe of Peace'

The "pipe of peace" thus passed back and forth this year between Capitol Hill and Germantown as negotiations proceeded on the '60 authorization bill had this effect on the bill itself:

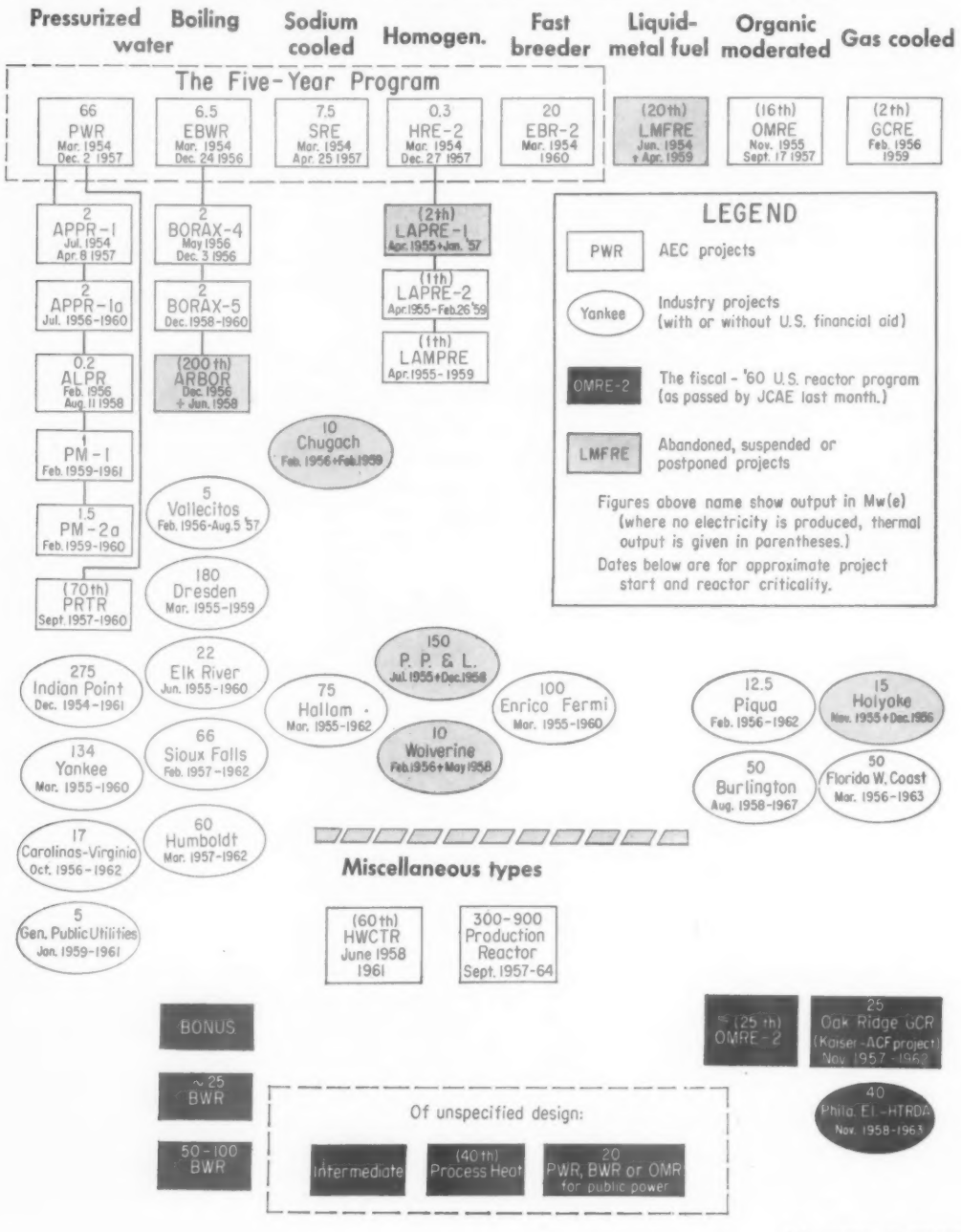
- There is no major project in the measure which is unacceptable to AEC, despite the threats of some JCAE Democrats to force through a large reactor program.
- AEC was given unaccustomed control over size, type, etc., of several of the nine civilian-reactor projects in the bill. For example, the high-power-density boiling-water reactor AEC will ask industry to cosponsor was described simply as a plant which "may be a boiling-water

prototype reactor in the size range from 50,000 kw(e) to 100,000 kw(e)." Three other proposed cooperative reactors were designated respectively as "a prototype reactor in the intermediate range," "a small power reactor," and another reactor prototype "in the intermediate size range."

• There is virtually none of the mandatory language in the bill of the type that distinguished authorization bills of the last two years. Rather, the bill contains phrases like "The Commission shall consider, but not be limited to the following [reactor] types" and "the Commission may, if the project is still deemed desirable, proceed with design, construction and operation" of reactors for which it gets no satisfactory proposal under the Second Round.

Probably the closest the bill comes to ordering AEC to do something it would rather not is a proviso attached to authorization of AEC's arrangement with Philadelphia Electric/High Temperature Reactor Development Associates on their advanced gas reactor (NU, Dec. '58, 17). As first proposed by a JCAE subcommittee (NU, June '59, 21), the proviso had been totally unacceptable to the utilities because it required reimbursement of AEC re-

'60 Reactor Starts Show Emphasis on BWR, Gas, OMR


Pressurized water
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Sodium cooled
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Fast breeder
Liquid-metal fuel
Organic moderated
Gas cooled
The Five-Year Program
66 PWR Mar. 1954 Dec. 2 1957
6.5 EBWR Mar. 1954 Dec. 24 1956
7.5 SRE Mar. 1954 Apr. 25 1957
0.3 HRE-2 Mar. 1954 Dec. 27 1957
20 EBR-2 Mar. 1954 1960
(20th) LMFRE Jun. 1954 ▾ Apr. 1959
(16th) OMRE Nov. 1955 Sept. 17 1957
(2th) GCRE Feb. 1956 1959
2 APPR-1 Jul. 1954 Apr. 8 1957
2 APPR-1a Jul. 1956-1960
0.2 ALPR Feb. 1956 Aug. 11 1958
1 PM-1 Feb. 1959-1961
1.5 PM-2a Feb. 1959-1960
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(2th) LAPRE-1 Apr. 1955+Jan. '57
(1th) LAPRE-2 Apr. 1955-Feb. 26 '59
(1th) LAMPRE Apr. 1955-1959
10 Chugach Feb. 1956+Feb. 1959
5 Vallecitos Feb. 1956-Aug. 5 '57
180 Dresden Mar. 1955-1959
275 Indian Point Dec. 1954-1961
22 Elk River Jun. 1955-1960
134 Yankee Mar. 1955-1960
66 Sioux Falls Feb. 1957-1962
17 Carolinas-Virginia Oct. 1956-1962
60 Humboldt Mar. 1957-1962
5 Gen. Public Utilities Jan. 1959-1961
150 P. P. & L. Jul. 1955+Dec. 1958
75 Hallam Mar. 1955-1962
10 Wolverine Feb. 1956+May 1958
100 Enrico Fermi Mar. 1955-1960
12.5 Piqua Feb. 1956-1962
15 Holyoke Nov. 1955+Dec. 1956
50 Burlington Aug. 1958-1967
50 Florida W. Coast Mar. 1956-1963
LEGEND
PWR AEC projects
Yankee Industry projects (with or without U.S. financial aid)
OMRE-2 The fiscal-'60 U.S. reactor program (as passed by JCAE last month.)
LMFRE Abandoned, suspended or postponed projects
Figures above name show output in Mw(e) (where no electricity is produced, thermal output is given in parentheses.)
Dates below are for approximate project start and reactor criticality.
Miscellaneous types
(60th) HWCTR June 1958 1961
300-900 Production Reactor Sept. 1957-64
BONUS
~25 BWR
50-100 BWR
Of unspecified design:
Intermediate
(40th) Process Heat
20 PWR, BWR or OMR for public power
(25th) OMRE-2
25 Oak Ridge GCR (Kaiser-ACF project) Nov. 1957-1962
40 Phila. El.-HTRDA Nov. 1958-1963

search-and-development aid if the utilities decided unilaterally not to build the reactor. However, the full committee modified it to allow abandonment without reimbursement if (1) AEC approves such abandonment or (2) it is dropped for reasons beyond the control of either party. Authoritative industry sources said this new proviso was acceptable to the utilities.

"I don't think," commented Sen. Anderson as the '60 program emerged from its Congressional trials, "that you'll ever get a program which includes all the things everybody would like to have. We tried to find a balance."

It is clear that such a balance was achieved, except, possibly, for the omission of any large-scale project. As it stands, the program gives the U. S. its first real gas-reactor program, schedules new construction in four different reactor areas (gas, organic-moderated, BWR and nuclear superheat), gives the military two new reactors (gas-cooled for the Army and a natural-circulation prototype for the Navy), and calls for design work on a heavy-water reactor, a nuclear-tanker reactor, a portable reactor for remote military use, and anything else AEC thinks promising. AEC reports on the D_2O and tanker designs are due at JCAE Apr. 1, 1960.

The measure also authorizes AEC to commit $7-million in U. S. funds for the joint research-and-development program with Euratom. AEC had asked $14-million but the smaller figure was accepted on the ground that little, if anything, more could be spent on the program before early next year.

AEC Projects. Major power facilities authorized for construction by AEC in '60 were: **1.** a second organic-moderated experiment at the Idaho testing station, $6-million; **2.** a $4-million low-temperature process-heat reactor, whose heat AEC might sell to the Interior Dept. for its saline water program, or to a non-governmental user; **3.** an $11-million nuclear-superheat reactor that AEC may build itself or in collaboration with industry; **4.** a $30-million gas-cooled reactor at Oak Ridge National Laboratory, ground for which was broken last month. Military and research facilities authorized included: **5.** an $18.5-million natural-circulation prototype for the naval reactor program; **6.** a $2.5-million portable gas-cooled prototype; **7.** a $5-million test plant for Army reactors, all in Idaho; and **8.** a $10-million high-flux research reactor at Brookhaven.

The bill also permits AEC to increase power output at Shippingport (150 Mw expected with the second core) at a cost of $5-million.

Cooperative Program. AEC was authorized to spend between $55.5- and $65.5-million to support public- or private-utility construction of a series of reactors.

Under the Third Round philosophy of the Reactor Demonstration Program—non-AEC ownership of the reactor—AEC can contribute research-development and waiver-of-fuel-use charges for a 50–100 Mw(e) boiling-water reactor, an intermediate-sized prototype of unspecified type, and unsolicited proposals from public or private utilities.

Under the Second Round philosophy—AEC ownership of reactor—AEC can support two reactor prototypes: a small power plant and an intermediate plant, types unspecified.

Five Reactors Proposed to Euratom for '63 Completion, Three Other Possibles for Later; Hirsch is Confident

The Euratom picture firmed considerably last month. The response to the call for preliminary reactor proposals was surprisingly good. The U. S., yielding to European cries that the Sept. 1 deadline for proposals was too short, agreed to an Oct. 20 deadline while maintaining plant completion targets of Dec. 31, 1963 and 1965.

When the sun went down over Brussels on the long-anticipated May 28th deadline day, eight replies had been received to Euratom's call for entries in the joint U. S.-Euratom power program: five "statements of intention" on power reactor projects, and three "foreshadowed" later projects. They were:

1. The SENN project on which work has already started: 160-Mw(e) boiling-water reactor by General Electric; target end-'62.

2. Netherlands: Provincie Noord Brabant Electriciteit. 150 Mw(e), completion target 1963.

3. Franco-Belgian: Electricité de France together with the Belgian utility group Centre et Sud, for a station at Chooz (pronounced show) near Givet on the Meuse river, on a finger of French territory extending deep into Belgium. Once earmarked as pressurized water, this reactor is now definitely stated to be of undecided type. 150 Mw(e), target 1963.

4. West Berlin: Berlin Kraft und Licht (BEWAG). 150 Mw(e), target 1963.

5. West Germany: AKS, the Stuttgart-based utility group, is reported down to a choice between a Babcock & Wilcox pressurized water and an Interatom (Atomics International) organic moderated reactor of 150 Mw(e).

Foreshadowed projects:

6. Electricité de France intends to propose another project for 1965 completion.

7. West Germany: SKW, the Hannover-based utility group, wants to build a large plant but says it doesn't see how it can meet the tight Euratom deadlines. If an extension were to be possible under the joint U. S.–Euratom program, SKW would likely choose a General Electric boiling reactor; indications are however that SKW will wind up building its reactor under the German 500-Mw(e) program, and in that case the choice would probably be between AEG of Germany (which has a cooperation agreement with GE) and Deutsche Babcock & Wilcox. Both have preliminary design orders from SKW (NU, Jan. '59, 20; Feb., 28). In either case target completion date would be 1965.

8. West Germany, the Munich group Gesellschaft für Entwicklung der Kernkraft in Bayern may produce a statement of intention, but its submission is still undecided.

No sites, reactor types or reactor suppliers were specified, except as noted above.

Hirsch Tours U. S.

A supremely confident Etienne Hirsch visited the U. S. with the presidents of the other two six-nation communities last month. The new President of Euratom, acting like a man who had measured the obstacles facing him and knows he can overcome them, met head-on the recent pessimistic talk in the U. S. and termed it "grossly exaggerated." Europe's 1980 power needs are unaffected by the improved coal and oil situation, he said; by then Euratom will require as much nuclear capacity as it has conventional capacity today—40,000 Mw(e). "We shall continue to approach the problem with a deep sense of urgency," he declared; "I can state emphatically that the cooperative program on which we

have embarked with your country is as indispensable as it ever was."

However the European utilities are still hagridden by shortness of time. Manufacturers' proposals for the Givet reactor, for example, are not due until Oct. 1, and with five months needed for evaluation, the final proposal will probably not reach Euratom until April 1960.

A number of utilities or utility groups were conspicuous by their absence from among those replying. Some of these were:

• The Belgo-Dutch group "Syndicatom" which had a project for a big station at Mol, Belgium, to serve both the north Belgian utility group Interescaut and utilities in southern Holland. One of the group's special problems, NUCLEONICS learned, was that competitive bidding required under the program was incompatible with the financial connections linking some of the sponsors with the Belgian manufacturing firm ACEC (Ateliers de Constructions Electriques de Charleroi), a Westinghouse licensee. The project may now accept its becoming ineligible for the program owing to the delay.

• West Germany's largest private utility, RWE (Rheinisch Westfälische Elektrizitätsgesellschaft) was also among the missing, although it did participate through its membership in the Hannover group.

Joint Research Board

One week after the deadline came announcement of membership of a U. S.–Euratom Joint Research and Development Board to review, evaluate and select proposals and to give over-all technical guidance to the reactor work under the joint program. The Board will have 12 members, six each from AEC and from the Euratom Commission, and 2 voting members: Amasa S. Bishop for the former and Jules Guéron of France, director general of Euratom's research division, for the latter.

The Board announced that more than 200 proposals and letters of intent for participation in the joint research and development program had been received from 63 U. S. and European firms, research and educational institutions as of May 15. The total amount represented by the definitive proposals is ~$37-million; the Board expects further proposals and $360,000 in contracts was to be let by June 30. Some of the combined proposers were trans-Atlantic groupings.

LATE & MISCELLANEOUS

LAPRE-2 Finished, LAMPRE Coming

The LAPRE-2 experiment at Los Alamos has been completed and pronounced "a complete success" (NU, May '59, 33). Its builders having learned from it all they hoped to, the uranyl-phosphate-fueled reactor is being operated no more and will be dismantled in a month or two. It had reached a maximum of 750 kw power, dictated by primary water circulating pump limits. No LAPRE-3 is presently contemplated. Meanwhile LAMPRE-1 (Los Alamos Molten Plutonium Reactor) is in final stages of assembly, NUCLEONICS learns; hope is for a cold critical run in a few months, full power by December.

Nautilus Refueled, *GW* Launched

The pioneer nuclear submarine *Nautilus* has entered Portsmouth (N. H.) Navy Yard for her second refueling (NU, Feb. '57, R5; May '57, 18). She is getting her third core at Portsmouth instead of the Electric Boat yard at Groton in order to spread around practice in core changing. Also last month, the Navy's ninth nuclear sub and first with Polaris missile-firing capability, *George Washington*, was launched at Groton, a record-setting 14 months after authorization. She is to be ready for sea trials by year's end.

GE Sells 'Sunrise' Reactor

General Electric last month sold its first power reactor under "Project Sunrise"—a 50-Mw(e), direct-cycle, forced-circulation, boiling-water reactor to be built by Consumers Power Co. of Michigan at Big Rock Point, Lake Michigan. Cost: $30-million. Completion target: 1962. Major development objective: a high-power-density, high-specific-power core capable of delivering 75-Mw of electricity after 4–5 years of operation. Prime contractor: Bechtel Corp. GE will supply reactor, instrumentation, core and generating equipment.

Consumers was undecided on a possible request to AEC for research-development aid.

The reactor is actually No. 2 under "Sunrise" (NU, Nov. '58, 19) but No. 1—the 50-Mw(e) reactor of Pacific Gas and Electric—was sold before Sunrise was launched. GE was predicting further Sunrise orders this year.

Wagonload of Reactor

Three pressure vessels, being fastened down in one gondola car, comprise major primary system components for Alaska's first reactor, SM-1a (ex APPR-1a) at Ft. Greely: pressurizer, top; reactor vessel, center; steam generator, bottom. Shipment left for 49th state from Alco's Dunkirk, N. Y., plant end May. Army's first field-installed power reactor, to be in operation next year, will have twice thermal output of Ft. Belvoir prototype from same size core, will supply all power and heat for Ft. Greely.

NAA, FW Drop Merger; NDA Talking?

North American Aviation (parent firm of Atomics International) and Foster Wheeler last month broke off negotiations that were to have led to merger this summer (NU, May '59, 26). No explanation was given; it is understood management problems such as exchange of stock, taxes, etc., could not be reconciled. Meanwhile several industry sources reported that Nuclear Development Corp. of America was talking merger with an unidentified larger firm. NDA President John Menke refused to confirm or deny, but said NDA had talked merger with more than one firm in the past.

AI Reactor for Walter Reed

Atomics International said it had designed a small biological research and medical-treatment reactor for the Walter Reed Army Medical Center, Washington, D. C. The 50-kw water-boiler will produce gamma rays, neutrons and radioisotopes; negotiations on a purchase contract with AI were still incomplete last month.

News in Brief

Decision on Canadian U Some Time Off

Jesse Johnson, chief of AEC's Raw Materials div., indicated last month that AEC will make no decision on the exercise of controversial purchase options for Canadian uranium until the options are about to expire on March 31, 1961. The options cover the period 1963–66 for contracts which run out in '62 and early '63. Canada will supply more than one-third of AEC consumption through '62. Johnson had hinted in April that the decision on substantial purchases from Canada after '62 might go against the Canadian suppliers (NU, June '59, 31). However, he said last month, AEC cannot commit itself until it knows more about (1) its post-'62 requirements, and (2) its commitments to purchase U. S. uranium after '62. AEC's need for weapons raw material after '62 depends on many factors, among them the international situation; the commercial demand for uranium is also a question mark. As for domestic purchase commitments in the '63–'66 period, AEC will not know what they will be until it completes current negotiations with U. S. suppliers looking toward a stretchout of deliveries between now and '62. Johnson said AEC is not now considering a stretchout of Canadian purchases, though he acknowledged that the Canadians have sounded out AEC on this possibility. Johnson said he had little fear that U. S. reserves would decline as a result of AEC's freeze of domestic purchases last year (NU, May '58, 25; March '58, 22). A considerable amount of ore-development work still being done, he said, may have the effect of maintaining current reserves of more than 80-million tons through '66.

AEC Adjusts Radioisotope Prices

Effective June 1, AEC has increased the price of six radioisotopes and reduced the price of four others, including widely-used carbon-14. The isotopes are produced and distributed by Oak Ridge National Laboratory. New prices are as follows (old in parentheses):

Carbon-14: $13/millicurie ($22–28)
Chlorine-36: $.50/mc ($1 for shipments through 149 mc)
Iridium-192 (sources): $6/curie plus source selection charge of $40 ($15 for first two curies, $2 each/additional curie)
Calcium-45 (high specific activity): $6.50/mc ($5)
Copper-64: $.80/mc ($.20)
Gold-198: $.06/mc ($.02)
Iron-59: $30/mc ($50)
Sodium-24: $7/mc ($2)
Yttrium-90: $3/mc ($2)

AEC Takes First Step Toward Reactor Safety Criteria

In a first cautious step toward eventual establishment of ground rules for judging reactor safety, AEC last month published a general statement of safety factors it considers basic to evaluation of reactor sites. Included was a discussion of exclusion areas for power and test reactors (radii of ¼ to ¾ mi), population density around a reactor (should be located up to 10–20 mi from large cities), meteorology, seismology and hydrology. In cooperation with the Advisory Committee on Reactor Safeguards, AEC's Hazards Evaluation branch in the Licensing and Regulation division has been working for some months on a program to mimimize the "judgment" factor in appraising reactor safety (NU, Feb. '59, 29); last month's site statement was the first formal move under this program. Industry comments were expected late in June, then AEC expected to get to work on specific parameters which, when adopted, would show a reactor builder what site standards he must meet to fulfill AEC safety requirements.

Notes on New Products, Firms

Radiation Dynamics, Inc., last month went into operation with the prototype of a small, low-cost electron accelerator for research and radiation processing which RDI claims will lower costs of commercial irradiation of plastics, rubber, etc., by 66–90%. The "Dynamitron" went on the line at RDI's Westbury, L. I., plant as reports circulated that **High Voltage Engineering Corp.** was nearing production of a small accelerator it has had under development for some time. RDI said four models of its machine were available for six months' delivery: a 1.5-Mev accelerator at 15 kw power; 1 Mev at 10 kw; 500 kev at 7½ kw; and 250 kev at 4 kw. Under development, RDI said, is a 3-Mev machine of 30-kw power. Work has begun with the Westbury machine on a dozen commercial research contracts, including plastic cross-linkage, rubber vulcanization and suture sterilization, the firm said. . . . On the West Coast, **Yuba Consolidated Industries** disclosed that it plans to go into production this summer on a number of nuclear materials and components: beryllium, zirconium, accelerators, fuel-element casks, control-rod drive mechanisms, shielding assemblies and reactor simulators. Yuba is already a supplier of a long list of nuclear items. . . . In Washington, D. C., **Medical Nuclear Consultants, Inc.**, has been formed to provide know-how in nuclear medicine for diagnostic, treatment and research programs in medical centers, hospitals, other groups and private practitioners. President Stanley H. Clark said the company has opened its headquarters office in Washington and branch offices in New York and Montreal.

Sylcor Purchases Interest in French Fuel Firm

Sylvania-Corning Nuclear Corp. has arranged to purchase an interest in a French nuclear fuels firm, subject to "necessary or appropriate governmental rulings and approvals." If the arrangement goes through, Sylcor will join three French manufacturers—Saint Gobain, Péchiney and S.F.A.C.—as owners of CERCA (Compagnie pour l'Etude et la Réalisation de Combustibles Atomiques). Sylcor and CERCA will share capability on fuel, control, shielding and blanket elements, plus other fuel-cycle components. Sylcor President Lee L. Davenport called the move the first American-European venture designed specifically to serve the Euratom market.

News Around the Atomic Beat

A new nuclear group, the **Institute of Nuclear Materials Management** (NU, May '59, 210), held its first annual meeting in late May at AEC headquarters in Germantown, Md. INMM officers include Ralph F. Lumb of Quantum, Inc., president; Richard S. Frankel of Nuclear Science and Engineering, vice chairman; William B. Thomas of Westinghouse Bettis, secretary; and Sheldon Kops of AEC's Chicago Operations Office, treasurer. Headquarters office has been established at Pittsburgh. . . . The Joint Committee on Atomic Energy has indefinitely postponed hearings planned for late June on the status and future of AEC's national laboratories (NU, June '59, 21). The hearings may be a first order of JCAE business in 1960. . . . AEC's **New York Operations Office** has moved to 376 Hudson St., New York City.

PRDC Case Ended

After almost three years, the case of three Detroit labor unions against the Enrico Fermi fast breeder has been closed: on May 26 AEC published a 100-page final decision confirming the reactor's construction permit (*see p. 60*).

ENEA Only 18 Months Old But Record is Impressive

PARIS

In the year and a half of its existence as a semi-autonomous administrative island in the cooperative waters of the OEEC,* the European Nuclear Energy Agency has piled up an impressive record. Fifteen nations are participating in three joint undertakings launched by the Agency, and the Agency is nearing completion of another venture for all 17 member nations —hacking out a clearing in the legal jungle of third-party liability. A capsule progress report:

A ROUNDUP Feature

- Preliminary design for the Eurochemic irradiated fuel processing plant completed and contract negotiations underway for construction of the plant at Mol, Belgium;
- Boiling heavy-water reactor at Halden, Norway, slated to go critical this summer (the reactor will be jointly operated by Euratom and six OEEC countries);
- Management board formed and first-year program set up for the Dragon experimental high-temperature reactor to be built at Winfrith Heath, England.

Credit for ENEA's running start goes to its governing body, the Steering Committee, which laid down some lines of possible cooperative efforts in nuclear energy as far back as 1956. In fact, negotiations by the Steering Committee to set up the Agency and the Eurochemic Company were carried out at the same time, so ENEA had itself a project from the outset. It also had the benefit of studies made by working groups set up by the Steering Committee, many of which were incorporated into ENEA's structure. What the Steering Committee did in effect, was to lay the groundwork for some possible joint atomic undertakings and then create ENEA to carry them through (NU, Aug. '56, R11; Jan. '58, 22).

ARMAND HAD KEY ROLE

The Steering Committee, and thus ENEA itself, resulted from an attack launched by OEEC in 1953 on Europe's pressing energy problem. Louis Armand, whose name always seems to pop up when Pan-European nuclear projects are concerned, analyzed the problem in broad outline for OEEC. His report emphasized two factors: the cost of energy was going up and the European shortage was growing into a threat. On the basis of Armand's report, OEEC set up an over-all energy policy based on economic considerations. It put a group of three experts headed by Leander Nicolaidis of Greece to work exploring possible lines of joint action in nuclear energy. From their work evolved the Steering Committee, executive body of the Agency which Nicolaidis still heads, and the first joint undertakings.

Anyone out to compile a "Who's Who in Nuclear Europe" could well start with the roster of ENEA. The Steering Committee alone includes the chairmen, or equivalent, of the atomic energy commissions of the 17 OEEC countries. Pierre Huet, former general counsel of the OEEC, heads the secretariat; he is supported by Einar Saeland of Norway as deputy director and Leo Kowarski of CERN as scientific adviser.

The pool of talent assembled under the ENEA banner is split on three levels. At the top policy level is the Steering Committee, which meets five or six times a year to review progress and explore new lines of action. Because ENEA is under the wing of OEEC, policy decisions, especially those that impose international obligations upon individual governments, must be approved by the OEEC Council.

At the second, or working level, are the groups of experts and the 40-man secretariat.

Management boards of the joint undertakings constitute the third level. ENEA does not directly administer the projects it sets up. The projects, like the Agency itself, are semi-autonomous.

ENEA's approach to its broad objective, promoting "togetherness" in nuclear energy when individual nations can't do the job alone, has from the outset been empirical. No master plan for joint action has been drawn up; instead the Agency has tried to set up projects which meet immediate needs of European countries and then to induce its member countries to participate. Under this approach, a project like the Eurochemic fuel processing plant becomes a natural. Any large-scale atomic power program depends to a considerable extent on fuel processing facilities; Eurochemic offered interested countries a chance to get in on construction of a pilot plant at a fraction of the cost of going it alone.

Twelve OEEC countries joined in the project, established Eurochemic as an international company with $20-million capital (Spain joined later as an associate, adding another $1.5-million.) Proposals of the study group that laid the foundation for Eurochemic set the plant's capacity at 100 tons a year, enough to meet Europe's needs, taking into account national plants, until 1963 or 1964. The group also specified a versatile installation capable of handling a variety of fuel elements and roughly indicated the process to be used in the plant.

EUROCHEMIC DESIGN

An international design team working at the plant site at Mol recently completed the preliminary design. For the extraction, the team specified a four-cycle process using TBP (tributyl phosphate) mixed with a hydrocarbon fraction. Final purification stages will use silica gel for uranium and ion-exchange columns for plutonium. Number of "head ends" necessary to convert the fuel elements to nitric acid solutions, a tough problem because of the variety of elements that may have to be handled, has not yet been definitely set. Eurochemic is querying the governments involved to find out what claddings and what degrees of enrichment it can expect, will base its final design on the replies.

With preliminary design completed, Eurochemic is now negotiating contracts for construction of the plant itself, which should be started in 1960, operating in 1962.

Although Eurochemic was ENEA's first joint undertaking, the emphasis on the Agency's activities to date has really been on applied research in reactor technology. Halden and Dragon, the second and third joint projects, involve reactors, and it is very likely that the next ENEA venture will be a third reactor, probably a heavy-water-moderated, natural-uranium type in Euratom territory.

Pierre Huet, ENEA's director, points out a number of reasons for this emphasis. To begin with, practically no European country has the money or men to probe by itself into all the promising types of reactors; joint action is a practical way to keep abreast in several types. Also, the entire end-result of an experimental reactor program —new data and new techniques—is available in full to every country that participates. In a joint power project, the major objective is kilowatts. For this reason, and others of course, ENEA has not pushed very hard

* Organization for European Economic Cooperation

for joint power stations, although one of its working groups did turn out proposals for four joint projects.

HALDEN AND DRAGON

ENEA is about ready to go on its first reactor project, joint operation of the boiling heavy-water reactor built by the Norwegian Atomic Energy Institute at Halden. The reactor is expected to go critical this summer. Six countries and the Euratom Commission will participate in a three-year operating program budgeted at about $4 million.

The Halden reactor, only boiling-water type in Europe and the first D_2O-boiling-water reactor in the world, eventually will supply process steam to a nearby paper pulp plant. The reactor cost $2 million to build, excluding fuel; price tag for the heavy water was $1 million. Steam production is scheduled for early 1960.

Still in the formative stage is the more ambitious Dragon project, a $38 million international program to investigate the use of high-temperature gas-cooled reactors for nuclear power stations. Its management board has been organized and the first year's program and budget sketched out. Big item in the project is construction at Winfrith Heath of a 10-Mw(th) reactor, slated to be completed in 1962. An international design team will draw up the working plans based on a British preliminary design.

THIRD-PARTY LIABILITY

ENEA also operates in a number of legal and economic areas that affect nuclear energy. Perhaps its most important achievement to date, in terms of furthering the industrial development of nuclear energy in Europe, is its third-party liability convention. This document, which ENEA hopes will be ratified this summer, represents a great step towards solution of a problem that has plagued Euratom in particular and other countries as well.

Guiding principle of the convention is that liability is absolute and channelled solely to operators of nuclear plants; suppliers and contractors are excluded from any liability. Limit of the operator's liability is set at a maximum of $15-million for an accident, and cutoff date for filing claims at 10 years. Although its financial limit is admittedly low (it can be reduced to $5-million by individual countries who desire to do so), the convention does provide a basis for ironing out the wrinkles of the liability problem. Euratom is pushing hard for ratification of the convention, and will probably supplement it with a scheme for government indemnity for accidents where damages exceed the $15-million limit.

Another convention on which ENEA expects to put a "Ratified—In Force" stamp this summer is the Security Control Convention. It provides for accounting for all fissionable materials used in international projects in OEEC territory and for inspection by Agency personnel.

MANPOWER

Top men at ENEA feel that the shortage of nuclear specialists, as much as anything else, may put the brakes on expansion of nuclear energy in Europe. To get its bearings in this important field, ENEA surveyed the existing training facilities and has, in the last two years, issued annual catalogs of nuclear training courses in Europe. ENEA has attacked soft spots turned up by the survey by organizing specialized courses at the better-equipped research centers in Europe. Sessions for university teachers were held at Harwell and Saclay in 1957 and will be repeated again this year. Also on the accomplished list are courses for industrial technical executives and a symposium on health physics methods. Under consideration now is a plan to provide brainpower and cash to several universities so that they can develop training programs in the principal nuclear subjects. ENEA is working closely with the OEEC's Office of Scientific and Technical Manpower in the latter project.

ENEA's inclination to cooperate extends outside the OEEC: the Agency maintains close relations with the other two large international nuclear energy organizations headquartered in Europe, Euratom at Brussels and the International Atomic Energy Agency at Vienna. Running across these three organizations, a casual observer might conclude that Parkinson's Law applied in the nuclear energy field. But actually ENEA, IAEA, and Euratom all have different goals and structures.

An obvious difference is membership (*see table*). Euratom comprises a tightly knit community of six nations working toward economic, and possibly political, federation. IAEA's membership blankets the world, includes countries from the Western and Soviet blocs, South America, Africa and the Far East. ENEA, with 17 OEEC countries as members and the United States, Canada and Spain as associate members, lies between the two.

Because all of Euratom's members are also ENEA members, relations between the two organizations have been exceptionally close; the Common-Market-Free-Trade-Area squabble has not spilled over into nuclear energy. Five of the "Six" are participating in Eurochemic and the Euratom Commission itself signed up for the Halden and Dragon projects. ENEA and Euratom worked hand-in-hand, practically, to set up Europe-wide health and safety norms that will be complemented by a system for exchanging data on ambient radioactivity.

Relations between ENEA and IAEA follow a different pattern. Although all ENEA members except Ireland are IAEA members, possibilities for cooperation in joint projects are limited because of the wide geographical spread of the International Agency's membership. But in the fields of health, safety, third-part liability and security control, the two keep in close contact and interchange information.

European Nuclear Energy Agency Membership

	ENEA	Euro-chemic	Hal-den	Drag-on	IAEA	Eur-atom	CERN
Austria	M	M	M	M	M		M
Belgium	M	M	Me	Me	MB	M	M
Denmark	M	M	M	M	MB		M
France	M	M	Me	Me	MB	M	M
West Germany	M	M	Me	Me	M	M	M
Greece	M				M		M
Iceland	M				M		
Ireland	M						
Italy	M	M	Me	Me	M	M	M
Luxembourg	M		Me	Me	M	M	
Netherlands	M	M	Me	Me	MB	M	M
Norway	M	M	M	M	M		M
Portugal	M	M			M		
Sweden	M	M	M	M	M		M
Switzerland	M	M	M	M	M		M
Turkey	M	M			MB		
United Kingdom	M		M	M	MB		M
Spain	A	A			M		
Canada	A				MB		
United States	A				MB		

M means Member; Me, member through Euratom; A, associate member; MB, member of IAEA and also of its Board of Governors

ROUNDUP

Isotope Development Program: $4-Million in First Year

On June 30 AEC's Office of Isotope Development completed the first fiscal year of its Isotope Development Program (IDP) after having pumped more than $4-million of federal funds into radioisotope exploitation.

In some respects, the first year of IDP was one of "baptism under fire": criticism came from Congress (is IDP necessary?) and from the radiation industry itself (why exclude radiation machines? and can't you give us patent rights?). There was also a rhubarb over annual savings from isotope use (NU, May '59, 35): AEC Commissioner Willard Libby, among others at AEC, has often estimated savings of at least $500-million; however, the National Industrial Conference Board could find only $40-million when it surveyed industry users under an IDP contract.

Nevertheless, the program's leaders feel they made a tremendous stride toward accelerating isotope use in assigning some 60 contracts to industry in low-level, high-level and educational areas of isotope development. Via another handful of survey contracts, they feel, they have identified the present areas of industrial uses and laid the foundation for increased development investment by both industry and by AEC in subsequent years of the program. Highlights of IDP's first year:

- More than $1-million in low-level research-and-development contracts were let in such varied fields as medicine, chemicals, food, textiles, soap, natural gas, steel, coal and rubber.
- Another $1-million in contracts were let in the high-level radiation field (large isotope sources), including development of reactors designed primarily for isotope production.
- Nearly $1-million was committed to promote development of training aids (courses, films, etc.) and the purchase of training equipment by colleges and universities.
- Tentative plans of AEC to build a $1.6-million process irradiator (NU, Oct. '58, 23), either alone or in cooperation with industry, were dropped for the present.
- A 15-man radiation advisory committee to AEC was named.
- $6.1-million was requested from Congress for the second year of the program.

First Year Contracts*

Contractor	Subject	Completion date	Amount
General			
National Industrial Conference Board	isotope economics	June '59	$63,000
W. H. Johnston Associates	industrial applications	June '59	104,000
Stanford Res. Inst.	medical applications	Apr. '59	64,000
Radioisotope applications			
Armour Research	X-ray sources	June '59	53,000
Tracerlab	gas analysis	June '59	48,500
General Atomic	isotope production	June '59	61,000
Nuclear Sci. & Eng.	industrial applications	June '59	22,500
Battelle	quality control and hydrocarbon chemistry	June '59	31,650
Nuclear Res. Corp.	nondestructive testing	Aug. '59	29,500
Crucible Steel	iron-alloy wear	Oct. '59	56,200
Martin Co.	small power sources	Oct. '59	220,000
Battelle	chemical process control	Oct. '59	49,700
Textile Res. Center	textile applications	Oct. '59	66,000
Associated Nucleonics	promethium-147 sources	Nov. '59	56,600
U. S. Radium	krypton-85 devices	Nov. '59	37,200
Nuclear-Chicago	chemical process control	Nov. '59	47,000
Midwest Res. Inst.	soap, detergent appl.	Nov. '59	14,900
Isotopes, Inc.	natural-gas applications	Nov. '59	23,400
Univ. of Chicago	genl. isotope research	Dec. '59	133,000
MIT	food-additive testing	Dec. '59	38,500
Alloyed Research Corp.	oxygen tracing	Jan. '60	49,700
Goodyear Tire	dating	Jan. '60	46,600
Isotopes, Inc.	natural-gas labeling	Feb. '60	45,000
Consolidation Coal	tritium labeling of coal	Feb. '60	74,700
MIT	general research	Feb. '60	115,000
Research Triangle Inst.	general research	Feb. '60	160,000
Textile Res. Inst.	textile applications	Mar. '60	14,200
National Canners Assn.	measure food residues	Apr. '59	38,800
High-level isotope sources			
Atomics Intl.	Hallam radiation facility	Dec. '58	76,000
Emerson Radio (CEM)	industrial survey	May '59	86,800
General Nuclear	production reactors	May '59	33,650
Rensselaer Poly	radiation chemistry	June '59	100,000
Brookhaven Lab	radiation engineering (fiscal '59 work)	June '59	190,000
Booz-Allen	isotope production by power reactors	Aug. '59	33,220
Associated Nucleonics	medical-supply gamma facilities	Sept. '59	79,000
Radiation Applications	polymer grafting	Dec. '59	43,500
	fission-product beta sources	Dec. '59	73,000
Battelle	polymer grafting	Feb. '60	63,000
Air Reduction	gaseous beta applications	Feb. '60	87,700
Battelle	hydrocarbon nitration	Mar. '60	36,000
Education			
Equipment grants	33 colleges, universities	———	604,416
Library of Congress	foreign literature survey	June '59	9,000
Nuclear-Chicago	basic lab manual	June '59	37,500
General Motors	basic industrial course	May '59	15,000
Army Pictorial Service	40-min. color film	Dec. '60	88,000
	Total		3,262,766

* Does not include 20–25 contracts still under negotiation in early June. The proposals, involving $800,000 in additional IDP funds, had been accepted by the Office of Isotopes Development but contract negotiations had not been completed.

NSEC Has 'IDP' of Its Own; Firm's Growth Explosive

The potential economic breadth of AEC's burgeoning Isotope Development Program (*opposite page*) has probably never been better analyzed than it was in Pittsburgh recently by the president of a firm whose future is tied in large part to isotope exploitation. In an interview with NUCLEONICS, Ronald A. Brightsen of Nuclear Science and Engineering Corp. explained his firm's view of the outlook for commercial radiation:

"Our business is based on a phenomenon (radiation) rather than a product. We've said we're going to work for everyone who is interested in radioactivity—applications, measurement and protection. That's a helluva lot of people."

It is no coincidence, then, that NSEC's list of commercial contracts reads a little like the Isotope Development Program's list—in breadth of penetration into the U. S. economy if not yet in total dollar value. The company is exploring isotope uses for steel, oil, food, chemicals, drugs, cosmetics, coal, railroads, utilities and utility suppliers and several government agencies.

NSEC celebrates its fifth anniversary this month as a research, development and service organization (both reactor and isotope development) and as a supplier of packaged isotopes. Its growth has been—and still is—explosive. The five employees of July 1954 are now more than 60; dollar value of orders has increased by an average 80% each year to an estimated $1-million this year; the company was in the black within 20 months of its beginnings and has been doubling profits each year since; projections based on its data-analysis program show a future growth-rate comparable to the current rate over at least the next 2–3 years; and there is reason to believe the firm may one day go into the manufacture of promising products developed by its own people.

Organization

NSEC is owned, managed and staffed by men of the "idea" type—young scientists and administrators who have put their know-how up for sale in a businesslike manner. In this sense, it is typical of a growing number of small but strong firms capitalizing on the seemingly unlimited commercial potential of radiation. Brightsen, who runs the company from a plain, cubicle-like office near the old Allegheny Airport, is himself only 34 years old.

The firm is largely internally owned, its stock spread among some 20 senior technical and administrative people and the board of directors. At one time Norden-Ketay Corp. was a major stockholder but this interest was returned to the stockholders when Norden-Ketay was acquired by United Aircraft Corp. a year ago. The only outside stockholder now is Lehman Bros., New York City investment bankers.

NSEC is organized into five major departments: chemistry, under Paul Kruger; biology and medicine, under Abe Edelmann; physics and engineering, formerly under Ralph Ely who recently resigned (NU, May '59, 35); marketing, under Bruce Beard; and finance, under Bob Sachs. Board chairman is Eugene Zuckert, former Atomic Energy Commissioner, who was elected after the death last year of Gordon Dean, former AEC chairman and a guiding light in NSEC's founding. Recently elected to the board were Paul Genachte of the Chase Manhattan Bank and Herbert Simon of Carnegie Tech; they succeeded Ely and Richard Frankel, formerly director and secretary-treasurer, who has moved to San Francisco as NSEC's Western sales manager.

Of the total of 60 employees, 75% are scientists—representing such varied fields as chemistry, biology, pharmacology, bacteriology, physics, engineering, physiology, etc.

West Mifflin Success Story

What are the "secrets" of NSEC's near-doubling annual growth rate? One is an accounting system which not only shows at any given moment where the company stands but also where it's going. Another is the unusually high percentage of propositions generated by the company itself, where there is no competitive factor.

"Probably only 20–30% of what we propose to prospective clients is by competitive invitation," Brightsen estimates. "In many cases, we approach a client because we know about his problems and think we can help him."

Thirdly, the company rarely experiences a declining position once it takes on a customer for the first time. Feasibility studies lead to research-and-development contracts for specific or general applications; these, in turn, have a way of blossoming into contracts for the design or construction of equipment or to another research-development program in a different area of a customer's business.

Fourthly, NSEC accepts business at a loss "extremely rarely" and it does little cost-plus-fixed-fee business. Most of its work for the government is done on a time-and-materials basis, which is normally more attractive than cost-plus business. Through either prime or subcontracts, the government is NSEC's largest customer, the percentage of total sales swinging to either side of the 50% mark as contract commitments change.

Nucleonics at NSEC

CHEMISTRY	Production Problems Process Tracing, Control Fission Product Release Rates Dosimetry Low-level Radioactive Analysis Activation Analysis Radioactive Gas Analysis
BIOLOGY and MEDICINE	Tracers Drug Assays Ultrasensitive Tritium Determinations Radiobiology Health Physics Environmental Radioactivity Surveys Urinalyses
PHYSICS—ENGINEERING	Basic Problems Instruments and Equipment Industrial Process Control Tracing Studies Waste Disposal Systems

ROUNDUP

World News

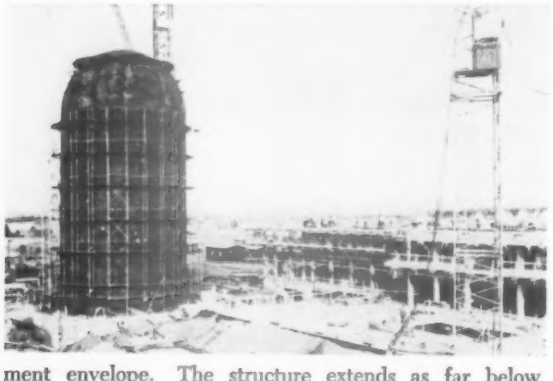
Massive Contamination Revealed in Mexico

An abandoned radiotherapy wing of the Mexico City General Hospital was discovered last month to be completely radioactive owing to careless storage for years of one gram of pure radium in bromide solution in a common office safe without any shielding radon. Half a gram was originally obtained 15 years ago for cancer therapy; seven or eight years ago another half-gram was added to the glass container in the thin-walled safe. Because of lack of radiotherapy experience and the poor design of the wing for work in that field, the wing was abandoned several years ago and locked—but the gram of radium was left in the safe to continue to contaminate the room, part of the yard and a section of the entire hospital wing, through the intermediary of the radon gas released.

After removal of the hot bromide into a 2½-ton lead cask, the entire two-story building will be torn down and all the building materials buried after thorough study. The NEC will also try to locate all persons who have been near the hot safe or in the hot room. Mexico's Nuclear Energy Commission plans intensive study of the case, feeling an exhaustive report would be of worldwide interest because there are few cases of such intense radium radiation over so long a period. The shocking case has loosed a clamor for rigid laws governing use of radioactive materials; NEC had been studying the matter and is redoubling efforts to draft strict rules.

Kahl Reactor Making Progress

West Germany's landscape is being stamped with the first of the characteristic steel domes that mark the U. S. atomic scene. Her first power reactor, the 15-Mw(e) boiling water reactor being built by RWE of Essen at Kahl, east of Frankfurt, nears completion of its containment envelope. The structure extends as far below ground as it does above it; the reactor will be below grade, the control room above. General Electric is furnishing the reactor to the prime contractor: AEG, a German electrical manufacturer. The plant is to start operating by end of 1960.



Cross-Licensing Across the Seas

Atomics International and English Electric have concluded an agreement providing for mutual technical assistance in the atomic field, including manufacture of reactors and reactor parts by both firms, exchange of technical advisory services, and training of EE personnel by AI in organic-moderated technology. . . . And General Electric Co. of Britain has signed a 10-year license agreement for close cooperation in the nuclear field with Germany's famed M.A.N. firm (Maschinenfabrik Augsburg-Nürnberg), a major heavy-machine builder. M.A.N. will get manufacturing licenses for all GEC (and Simon Carves) nuclear patents, and in return will pay GEC a capital sum plus a service fee per kw of guaranteed electrical output from nuclear power plants ordered from M.A.N.

Germany Starts Atom Forum

"Deutsches Atomforum" has been established with headquarters in Düsseldorf by four organizations working on peaceful uses of nuclear energy; aim is coordination of peaceful research and utilization of nucleonics and joint representation of member group in international meetings. The founders are: Working Group for Nuclear Techniques, Düsseldorf; German Association for Atomic Energy, Bonn; Atoms for Peace, Munich, and Physical Study Group, Düsseldorf.

Plutonium Meeting in France Next Year

The French Society for Metallurgy is organizing an international symposium on the metallurgy of plutonium, to be held April 19–22, 1960, at Grenoble.

Turkey Buys AMF Pool

First country to sign a research bilateral with the U. S., Turkey became the twenty-first to order its first reactor. AMF Atomics got the order to build a $3-million nuclear research center near Yesilkoy airport at Istanbul, overlooking the Sea of Marmara. The center featuring AMF's 19th reactor sale, a 1-Mw pool, is for '61 completion.

Fuels Across the Seas

Mallinckrodt Nuclear Corp. of St. Louis has the order to deliver ~20,000 lb uranium dioxide to fuel the RWE reactor being built at Kahl (*see photo*). . . . AMF Atomics (Canada) Ltd. has shipped the first fuel elements exported from Canada—290 rods valued at $400,000 and containing ~16,000 lb natural uranium—for Switzerland's second, heavy-water, research reactor under construction at Würenlingen.

IAEA Items

Agreement on the main features of a draft international convention on civil liability and state responsibility for nuclear hazards was reached by a 10-man IAEA experts' group. They will meet again this summer to seek agreement on points not yet settled . . . Scientists from 20 nations met in Vienna last month to discuss qualitative analysis by radioactivation . . . Prof. Arkady N. Rylov of the Soviet Union has been named Deputy Director General for Training and Technical Information, succeeding V. V. Migulin (NU, March '58, 26).

CERN Admits Austria

Austria became the 13th member state of the European Organization for Nuclear Research (known by its French initials as CERN) at the 13th session of the Council of CERN. The Council also heard that the 25-Bev proton-synchrotron CERN is building at Meyrin near Geneva is on schedule and will start up in late '59 or early '60.

Atomic Age Comes to Africa

Africa's first reactor went critical last month atop Mt. Amba 15 mi south of Leopoldville on the Congo river in Belgian Congo. It was the Univ. of Lovanium's General Atomic Triga research unit (NU, Nov. '58, 26).

Reactor News

MARTIN, KAISER GET AEC CONTRACTS

Two previously-announced AEC reactor-building selections got contracts last month. Martin Co. signed a cost-plus-fixed-fee contract to "design, develop, construct, install and test-operate" the Sundance, Wyo., PM-1 modular package power plant (NU, March '59, 25). Estimated cost of the 1-Mw(e)-plus-2-Mw(th) plant is $5,387,450. . . . And Kaiser Engineers signed a cost-plus contract estimated to be worth $100-million to build the new production reactor at Hanford (NU, June '59, 29). Most of the work will be done under lump-sum subcontractor arrangements. Preliminary work will start this summer, but heavy construction only in summer 1960; initial operation is set for October 1962.

RICKOVER REVIEWS PWR'S FIRST 18 MONTHS

"We have now operated [PWR] for 1½ years on the first charge of uranium and produced about 325-million kwh of electricity as of May 15, 1959," Vice Admiral H. G. Rickover told the American Public Power Assn. "The plant has operated at full power for over 4,000 hr; two full-power runs of 1,000 hr each and one of about 2,000 hr have been completed. In addition to accomplishing an extensive and varied test program, the plant has demonstrated ability to perform well both as base-load or a peak-load station [and] that it can be started up and shut down more rapidly and can accommodate more severe load transients than a coal-fired station." Rickover disclosed that, because PWR's second core may produce 150 Mw(e) (NU, May '59, 25), he had asked AEC for funds to make necessary changes in the reactor plant to increase capacity; and that AEC was conferring with Duquesne Light Co. concerning installation, at the latter's expense, of additional turbogenerating capacity. Rickover also flayed as "meaningless" attempts to estimate "cost of atomic power" from PWR costs: "Trying to predict the eventual cost of commercial atomic power by comparing the money spent on the developmental Shippingport plant with the electricity produced there is like the Wright brothers trying to predict commercial air-freight costs from the money spent and the distance flown by their first airplane at Kitty Hawk."

LOCKHEED OFFERS PACKAGE REACTOR

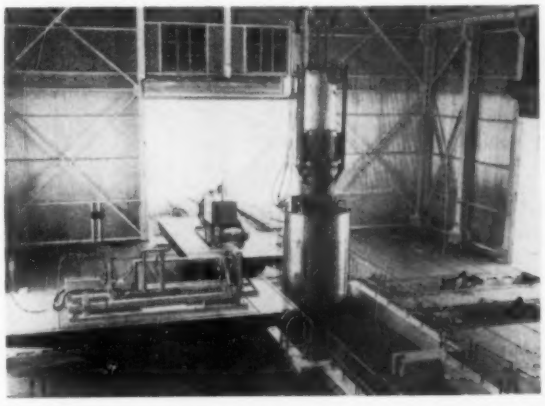
Joining Alco and Martin in the airliftable package reactor business, Lockheed Aircraft Corp.'s Nuclear Products Branch placed on the market a 1-Mw(e) pressurized-water plant. The 960-ton plant is designed for shipment aboard 16 Lockheed C-130 Hercules cargo planes that could deliver it anywhere in 1½ days; it could operate 90 days after foundations are completed. Twenty men in three shifts could operate it around-the-clock. Besides the 1 Mw of power, the plant produces 2 Mw of heat. Stearns-Roger Mfg. Co. of Denver and American Hydrotherm Co. of New York are nuclear subcontractors. Cost of the plant was not disclosed.

BIG-REACTOR PROGRESS NOTES

At **Dresden**, internal hardware—control rols, piping, etc.—is being installed in the reactor vessel and the instrumentation job is proceeding on schedule. The turbine is 60% erected. Commonwealth Edison's project chief Joe Poer says construction should be finished, and fuel loading start, about October 1. . . . The 150-ton, stainless steel plug that will seal the **Enrico Fermi** reactor vessel was delivered by special railroad flatcar to the site and has been installed. The 10-ft dia × 12 ft high cylinder is packed with borated graphite for shielding. A year-long program of non-nuclear testing of the nuclear components began last month . . . Westinghouse completed or was nearing completion of the turbines and generators for both **Yankee** and **Indian Point.**

RER CRITICAL, TESTED FIVE MONTHS

The Radiation Effects Reactor at the Georgia Nuclear Laboratories, operated by Lockheed for the Air Force, went critical last Dec. 14 and has successfully completed five months of testing. The 10-Mw(th) testing reactor,



built by General Electric, began its intended function of testing aircraft systems and components last month. The Air Force, however, will not keep the unit busy full-time and has made it available to other government agencies or their contractors for testing radiation effects (NU, Jan. '58, 26); Lockheed said it had received over 50 inquiries for its use in electronics, hydraulics, magnetics and chemical propellants.

LOS ANGELES UNIT SEEKING REACTOR

The Los Angeles Department of Water and Power, which has been ogling nuclear power since 1955, went to industry for bids on a small but advanced boiling-water reactor, then found itself hoist on the horns of a dilemma. LADWP asked six firms to bid: Westinghouse, General Electric, Babcock & Wilcox, Combustion Engineering, Allis Chalmers and ACF Industries. Because of the purchase of ACF by Allis, LADWP extended the deadline for filing bids from May 27 to July 1. Its dilemma is one familiar to public and municipal groups: financing. LADWP needs U. S. financial aid, but its chosen reactor—a prototype forced-circulation boiling water, 25 Mw(e) initially and 50 Mw from later cores, aiming for high power density and long burnup, and extrapolatable to a 200 Mw(e) scale-up—doesn't fit into any existing program. LADWP can allocate up to $10-million, but cost of its reactor is estimated, prior to receipt of industry bids, at $14-million. LADWP would like an extension of AEC's second-round plan under which AEC places the construction contracts and retains title, at least initially, to the reactor.

X-10 TO BE ANNEALED, DISMANTLED

Oak Ridge National Laboratory is preparing to anneal the X-10 graphite reactor for the first time to release Wigner energy prior to dismantling it. The 3.8-Mw pile, now an isotope maker and originally a Hanford prototype, has been in continuous operation longer than any other reactor in the world—since November 1943.

LATE & MISCELLANEOUS

Piqua Contracts Signed

AEC last month signed a $1-million, five-year operating contract with the City of Piqua, Ohio, and a $7.7-million construction contract with Atomics International, covering the 11.4-Mw(e) Piqua organic-moderated reactor. Over-all cost to AEC including research-development is put at $14.1-million. Construction is expected to start when AEC completes formal review of the project after a public hearing; completion target is October, 1961. Piqua had run into trouble earlier when AEC's Advisory Committee on Reactor Safeguards objected to the original site (NU, Oct. '58, 27); it later gave provisional approval but commented that it "does not look with favor upon the location of power reactors immediately adjacent to populated areas."

IAEA to be Fusion Center?

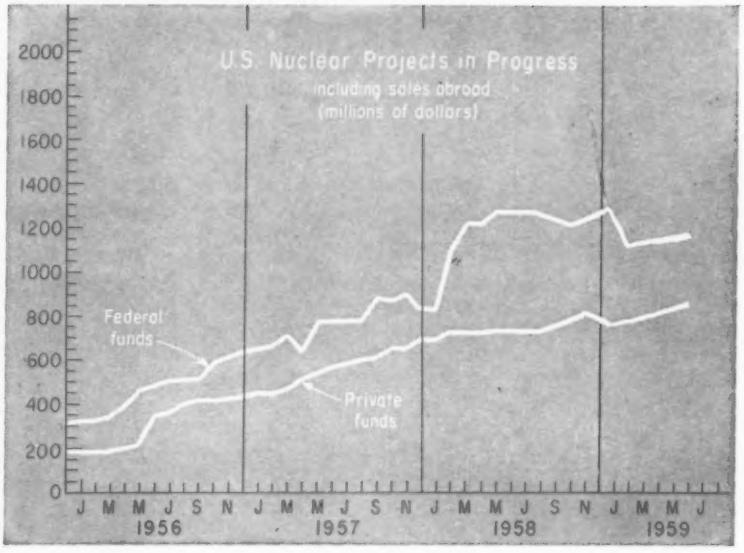
A strong recommendation that the International Atomic Energy Agency become the world focal point for exchange of information on fusion and plasma physics progress was made by IAEA's Scientific Advisory Committee. This seven-man group suggested IAEA found an international scientific journal on fusion progress and convene an international scientific conference in this field. The committee's U. S., British and Soviet members all pledged that they in their individual capacities would try to obtain strong support for this activity from their respective governments.

France's G-3 Critical

The second big graphite-moderated, CO_2-cooled dual-purpose reactor at Marcoule, France—G-3—went critical June 11, and should reach full power by year's end. G-2, its identical twin, has started supplying 30 Mw(e) full power to the French grid (NU, Aug. '58, 19).

Trawsfynydd to Fifth Group

As forecast (NU, June '59, 23), Britain's fifth nuclear consortium, Atomic Power Constructions Ltd., got its first job: to build the U. K's fifth and largest civil nuclear power station at Trawsfynydd, Wales. The two-reactor station—550 Mw(e) total output—will cost $182-million and use pumped-storage of coolant water with Ffestiniog Reservoir. It will be completed in 1964.



NUCLEONICS Statistics of the Month

	Latest month	Month ago	Year ago
Nuclear Contracts *—			
Contracts awarded for federal projects ($10)	129,265	6,107	2,842
Proposed construction, privately-owned ($10)	0	0	0
Contracts awarded, private work ($10)	0	0	13,660
Backlog of private projects ($10)	285	285	249
Isotope Use †—			
Applications for isotope use	651	902	578
Cumulative total of isotope users	4,867	5,028	3,750
ORNL shipments (curies)	63,900	13,443	n.a.
Public and private export shipments	276	128	238
Employment †—			
AEC employment	6,676	6,666	6,905
Construction and design contractors' employment	7,490	10,093	10,265
Total operating contractors' employment	104,434	104,629	113,355
Production workers	51,761	52,130	51,848
Research and development employees	47,254	46,987	44,760
Miscellaneous workers	5,419	5,512	6,482

U. S.-built Reactors ‡—

	Operating	Building	Contracted
Power, domestic	1	7	6
Power, for export	0	3	2
Power experiments and pilot plants	6	5	0
Military and naval	10	44	5
Research and test, domestic	58	21	47
Research and test, for export	14	14	8
Total	89	94	68

Foreign-built Reactors ‡—

Power, domestic	10	28	16
Power, for export	0	2	1
Research and test, domestic	34	11	11
Research and test, for export	8	6	0
Total	52	47	28

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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A.D.C. Overall amplifier gain — 1,000. Integral linearity of analog to digital converter is less than ±1% for channels 5 through 128.

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RCLiac 128 Accessories Include:

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The RCLiac 128 Channel Scaler-Analyzer is the ultimate in transistorized reliability as it performs every operation from scintillation spectroscopy through gross counting. Rugged, Compact and Portable, the RCLiac 128 may be used both in the field and the laboratory as a 125-channel scaler or a 128-channel analyzer..

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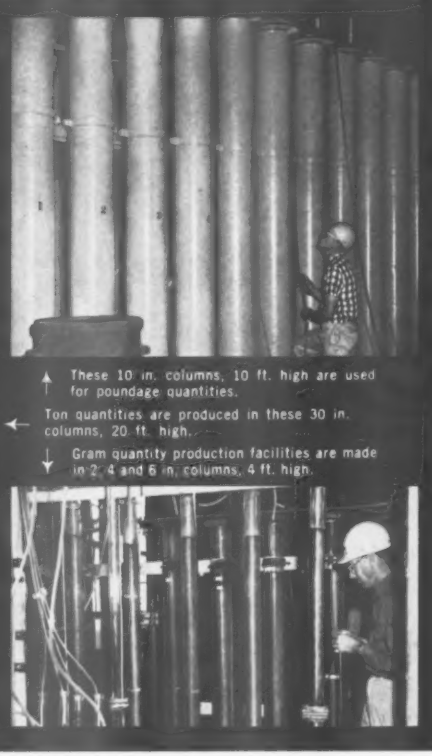

These 10 in. columns, 10 ft. high are used for poundage quantities.

Ton quantities are produced in these 30 in. columns, 20 ft. high.

Gram quantity production facilities are made in 2, 4 and 6 in. columns, 4 ft. high.

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Production Facilities: Until recently, the scope of Michigan Chemical's rare earth manufacturing has been classified. Now it can be told that its production units are the world's largest — with nearly 200 ion exchange columns 30 in. by 20 ft. high devoted to the manufacturing of tonnage quantities alone. In another section of this plant are 10 in. columns for the production of the less-abundant rare earth elements such as lutetium, thulium and holmium. Also, in our pilot plant are 2, 4 and 6 in. columns, shown right, which are used mainly for experimental work. A wholly new manufacturing plant is in operation producing rare earth metals in commercial quantities.

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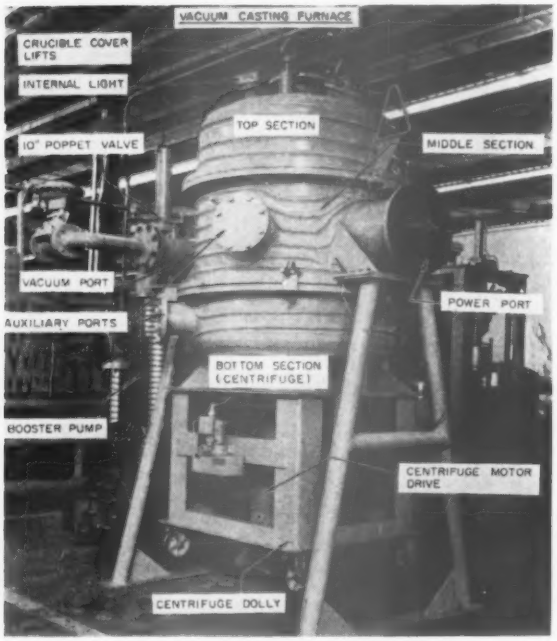
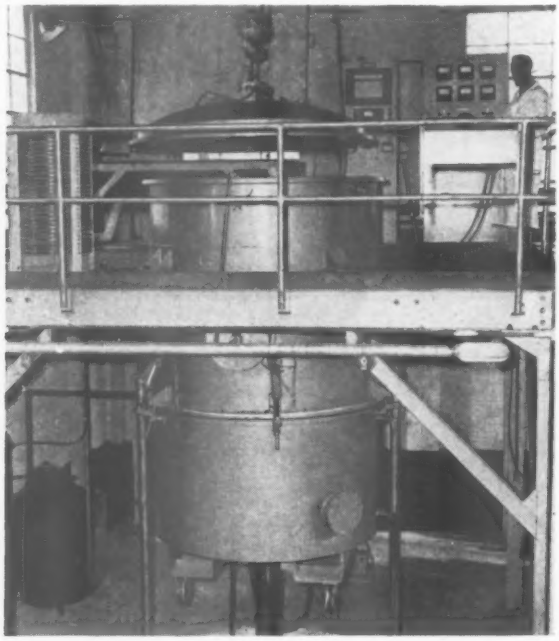
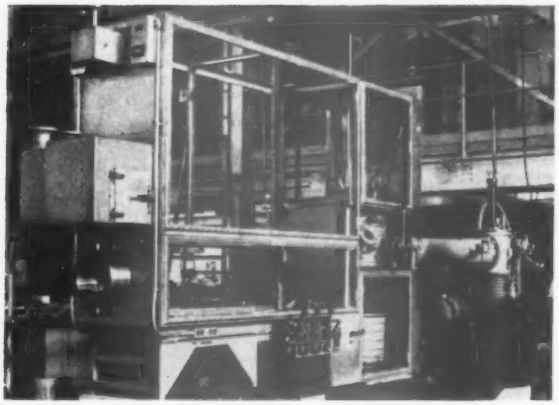
RADIOACTIVE MATERIAL HANDLING investigations are safely carried out with this Stokes prototype vacuum furnace. It is remotely operated by manipulators and other external controls. This installation represents another specific requirement met through Stokes flexibility.



URANIUM MELTING ON A PRODUCTION BASIS is accomplished by this Stokes induction melting furnace. Designed for safety and convenience, the furnace is serviced from the top and features a removable bottom section to facilitate handling of poured materials. It is typical of Stokes inherent flexibility.



nuclear flexibility



PLUTONIUM MELTING AND CASTING will soon be easily accomplished by this Stokes vacuum furnace being assembled for shipment to customer's plant. The entire system will be enclosed within a vacuum dry box for "clean handling" and operation: another example of Stokes design concept flexibility.

Metallurgical investigations are leading to new, practical applications: plutonium melting and casting, uranium melting on a production basis and new methods of handling radioactive materials . . . are just a few. At Stokes, extensive design experience and manufacturing facilities work hand-in-hand to make these developments possible. Stokes pioneered in the application of vacuum metallurgy to the nuclear field. In the modern Stokes laboratory, vacuum melting, casting, heat-treating and pelletizing experiments are providing new methods of overcoming traditional bottlenecks.

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Photo courtesy Phillips Petroleum Company

A Phillips Petroleum Company technician observes radioactive metallurgical specimens through a Kollmorgen Hot Cell Periscope installed at the Materials Testing Reactor Hot Cell, National Reactor Testing Station. The periscope helps determine characteristics such as tensile and impact strength, hardness, weight and density changes. Macrophotography of specimens is also performed through the periscope.

Radioactivity, caustic fumes, blast forces, inaccessibility and other adverse conditions hamper observation and inspection. To overcome these conditions, more and more installations in a widening range of industries are using Kollmorgen remote viewing instruments. Kollmorgen specializes in the design and manufacture of instruments and systems for detailed observation under difficult or apparently impossible circumstances. Most of these devices can be readily adapted to photography or television.

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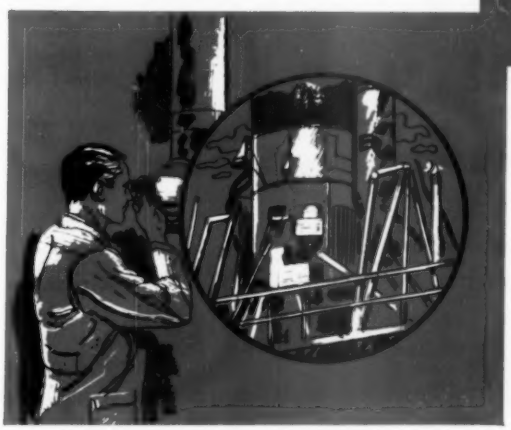
and from Cape Canaveral to the North Pole



The Nautilus and her sister ships of the Atomic Fleet, like most other U.S. submarines, are equipped with Kollmorgen periscopes. These instruments require highly precise optical, mechanical and electronic components.

Kollmorgen Bunkerscopes are used at Cape Canaveral for observation of missile launching operations and static tests. Bunkerscopes allow detailed observation from a considerable distance with no danger to the operator. Images appear in bright, clear, natural color. There are no maintenance costs with these Bunkerscope operations.

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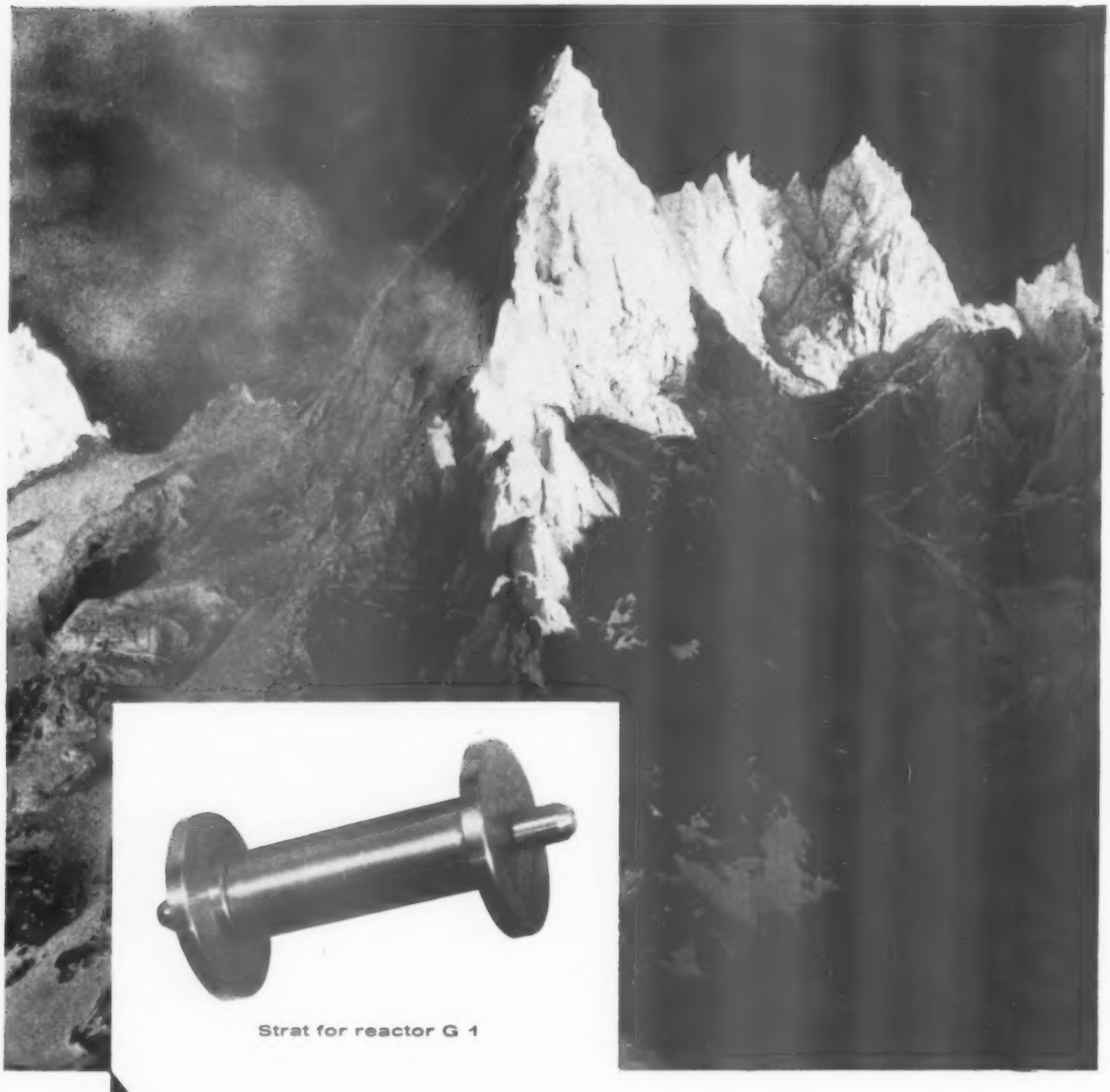

Strat for reactor G 1

Beryllium

Nuclear purity flakes
(metallic impurity < 3000 p.p.m. Boron ⩽ 2 p.p.m.)

Also ready for delivery :

Powdered, molten metal blocks, or sintered into sheets, bars, tubes or finished products.

PECHINEY Division Applications Atomiques
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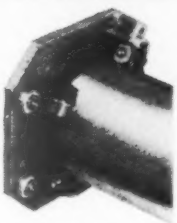
many new developments

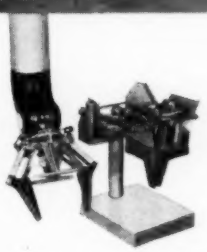
INCREASE PERFORMANCE, RUGGEDNESS, RELIABILITY

CRL manipulators... as obedient as your hand

Central Research Laboratories brings you important refinements in lateral rotation, azimuth assembly, wrist joint, tong, handle, roller mounts, load hook, and booting. Each is the result of CRL's continuing program to give you the finest in master-slave manipulators . . . manipulators which duplicate the natural motions of the operators' hand. Many of these improved features can be added to manipulators already in service. This program of improvement without obsolescence plus CRL's policy of immediate shipment on spare parts insures continued customer satisfaction.

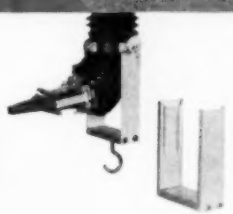


Improved *roller mount:* More rugged, more serviceable, less wear on through tube.

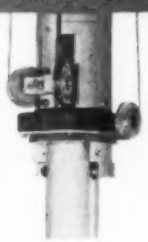


Improved *wrist joint, tong,* and *tong jig:* Greater protection of gears, more rugged, easier interchange.

Improved *handle:* More rugged, more satisfactory control of separation indexing and squeeze motion lock.



Improved *booting* and *load hook: Partial or* complete booting possible, load hook fits on booted or unbooted arm.

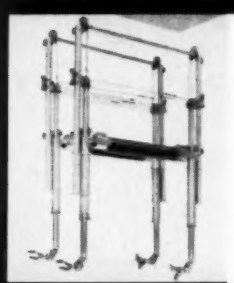


Improved *azimuth assembly:* Eliminates exposed rollers, provides greater "Z" motion or shorter collapsed length.

for thru-wall installation

CRL MODEL 8

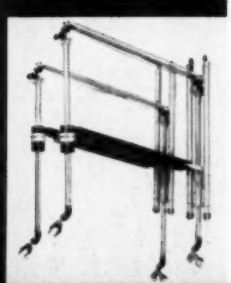
Thru-wall installation for intermediate to high-level shielding. Separation indexing and lateral rotation keeps operator close to window with full visibility over large area. Easy to relocate —one man with a light crane can remove and relocate in less than five minutes.



for over-wall installation

CRL MODEL 4

General purpose — for installation over a barrier wall or through ceiling opening of protective enclosure.



for restricted-space installation

CRL MODEL 7

Space saving, light weight — for use in "junior caves" or over thin walls where minimum clearance and easy portability are important factors.

Central Research Manipulators from basic Argonne National Laboratory designs

write today for complete information to:

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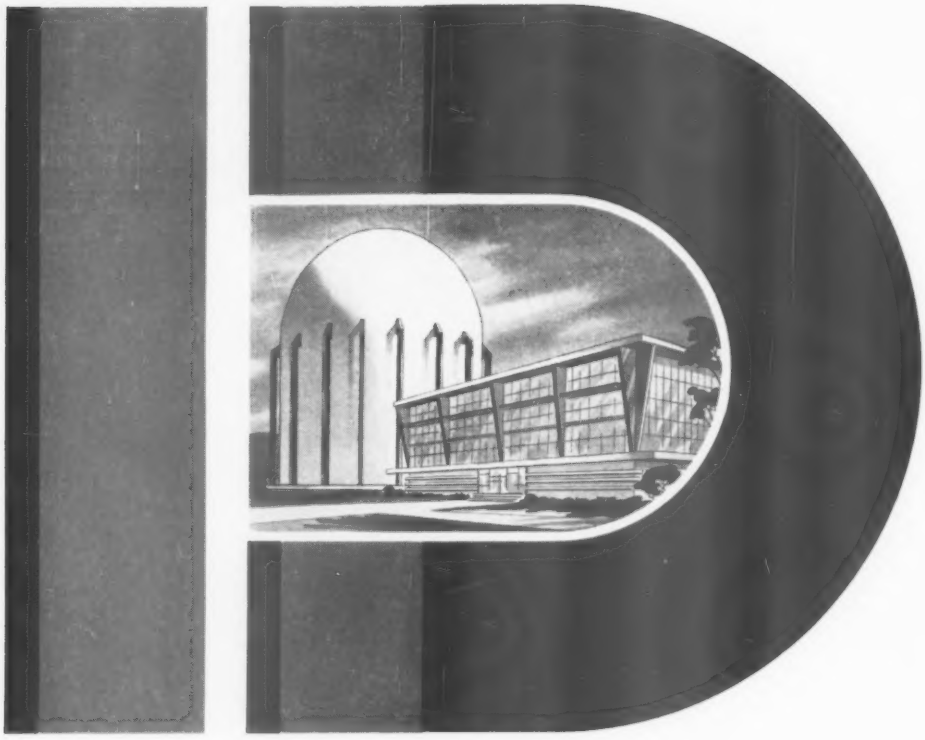
Red Wing, Minnesota, Dept. 102



Little Gypsy - - - first computer controlled electric power plant!

The electric power industry took a giant step toward safer and more efficient plant operation with the announcement that the new 230,000 kw Little Gypsy Station of Louisiana Power & Light Company will be completely automatically controlled by a Daystrom digital computer control system. The techniques inherent in the system are directly applicable to the requirements of the atomic energy industry. A case in point is the 2000-point, solid-state digital data scanner system delivered by Daystrom to General Electric Company's nuclear propulsion test group at Idaho Falls.

The decision to go ahead with the Little Gypsy project was backed by a year's operational experience with a Daystrom computer operating on-line at LP&L's Sterlington Steam Electric Station.

The original Sterlington installation, delivered over a year ago, came about through the combined engineering efforts of Louisiana Power & Light Company, Ebasco Services, Inc., design and consulting engineers for LP&L, and Daystrom Systems.

The Sterlington computer system performance has demonstrated for the first time the reliability and utility essential to the stringent requirements of overall control responsibility. This field operating experience permits Daystrom to guarantee system operational availability of more than 99%. The uncompromising criterion of design which makes this performance possible dictates the complete elimination of vacuum tubes and moving parts.

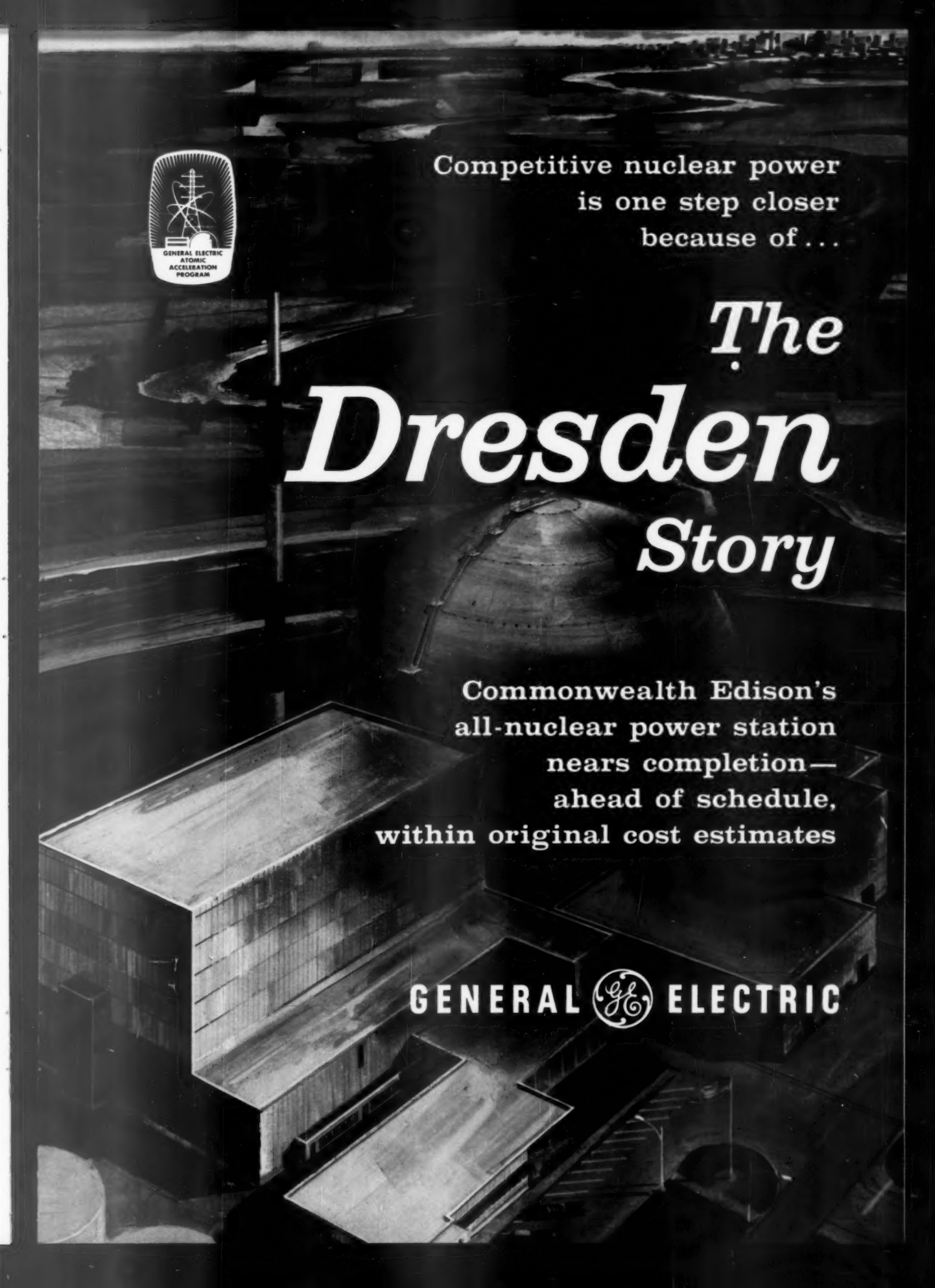
The Daystrom computer is but one example of Daystrom's design and engineering capabilities in the solid-state, magnetic and digital areas. The services of this specialized engineering group are available to the nuclear industry to solve their special instrument and control problems. For conference arrangements, write or telephone Daystrom Systems, Dept. A-109, Miramar Road, La Jolla, Calif. GLencourt 4-0421.

INPUT CONSOLE—STERLINGTON COMPUTER.

DAYSTROM SYSTEMS

DIVISION OF DAYSTROM, INC.

Reliable computer control systems


GENERAL ELECTRIC
ATOMIC
ACCELERATION
PROGRAM
Competitive nuclear power
is one step closer
because of . . .
The
Dresden
Story
Commonwealth Edison's
all-nuclear power station
nears completion—
ahead of schedule,
within original cost estimates
GENERAL ELECTRIC

The Dresden Story: ahead of schedule,

DEVELOPMENT AND CONSTRUCTION COSTS for Dresden are within the original estimate made by General Electric prior to contract signing in 1955, showing that boiling water reactor costs can be forecast accurately.

DRESDEN—THE NATION'S LARGEST ALL-NUCLEAR POWER PLANT at 180 mw—is scheduled for operation early in 1960. Here, the 190-foot-diameter steel containment sphere begins taking shape in September, 1957.

Dresden Project experience will demonstrate the lower total energy cost potential of the boiling water reactor

The Dresden Nuclear Power Station being built for Commonwealth Edison of Chicago and the Nuclear Power Group, Inc.,* will provide 180 mw of electrical power in 1960. Design is now 100% complete, and construction 83% complete on this country's largest all-nuclear power plant. Construction is six months ahead of schedule, costs within original estimates. Engineer-constructor for the station is Bechtel Corporation. Project experience at Dresden will help develop the lower total energy cost potential of the boiling water reactor system, notably in the area of reduced capital costs.

The Dresden design added to other General Electric atomic experience shows that capital costs for the boiling water reactor are lower than for any other type of proven reactor because:

1. Steam flows directly from the reactor to the turbine, permitting elimination of expensive and space-consuming heat exchangers and an auxiliary system.

2. The use of water as a coolant is a well-known technology, and more conventional materials can be used.

3. Simplicity of the boiling water reactor cycle allows the design of a compact plant, saving construction time and materials.

Dresden experience enables General Electric to quote firm prices for BWR plants because of known technology and confirmed design. An explicit endorsement of this ability was the choice of a General Electric 150 mw(e) boiling water reactor plant for Italy's Garigliano nuclear power plant (SENN) over all competitive reactor systems. The selection, made by three teams of independent power plant and nuclear experts, was based on demonstrated capability, power-producing potential, and low total power generating costs of the BWR.

Dresden—a milestone on the road to competitive nuclear power—reaffirms General Electric's conviction that the boiling water reactor will achieve economical nuclear power faster and at lower cost than any other reactor system.

*American Gas & Electric Service Corporation, Commonwealth Edison Company, Pacific Gas & Electric Company, Union Electric Company of Missouri, Illinois Power Company, Kansas City Power & Light Company, Bechtel Corporation, Central Illinois Light Company.

Progress Is Our Most Important Product

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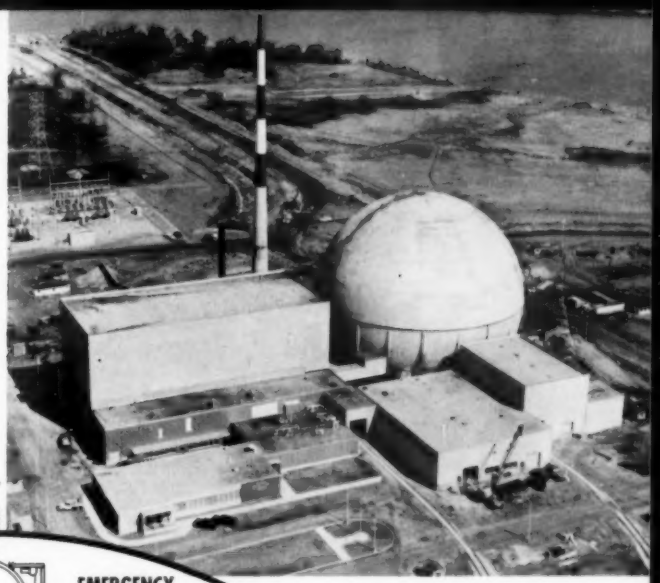
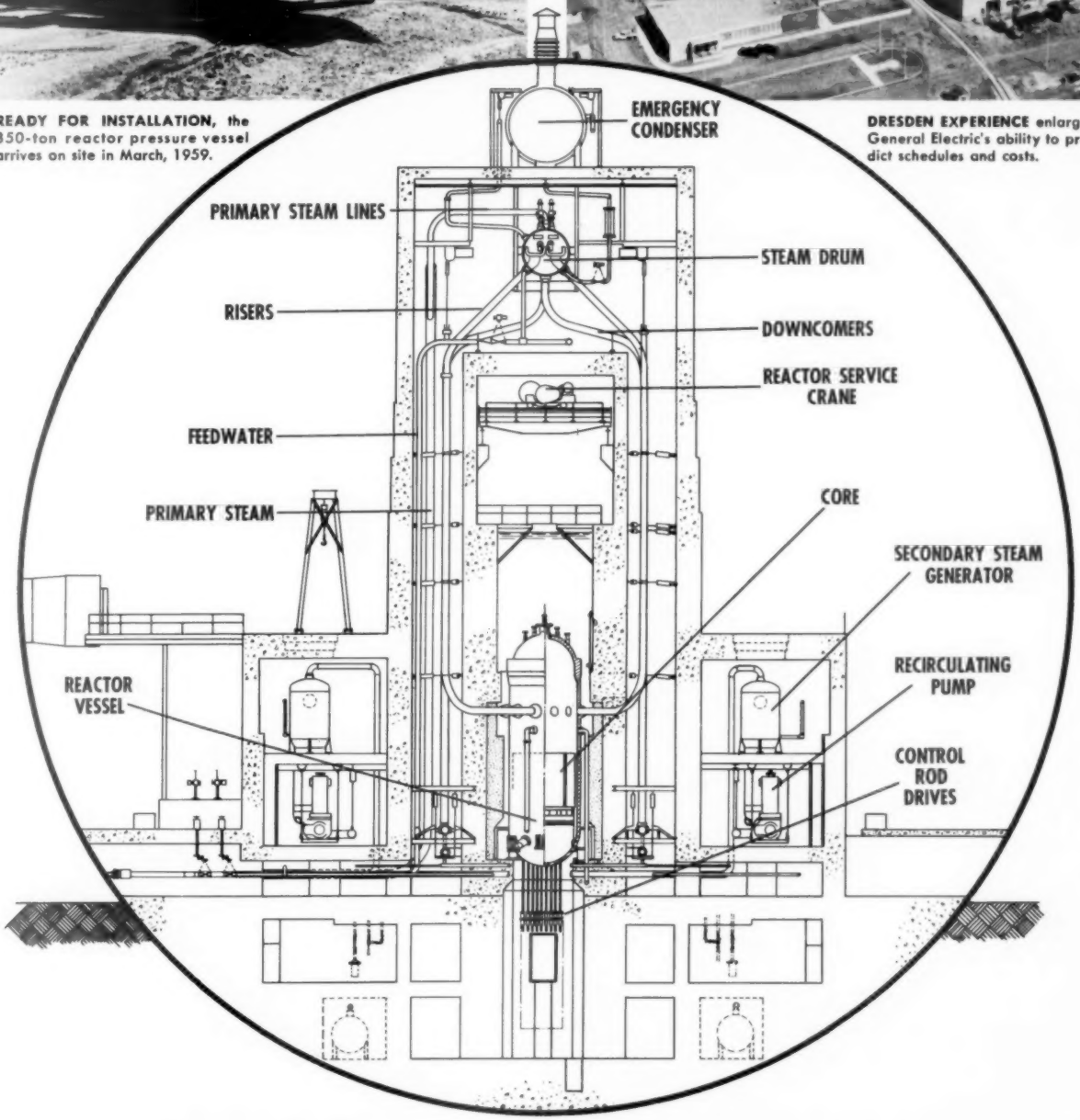
within original estimates

READY FOR INSTALLATION, the 350-ton reactor pressure vessel arrives on site in March, 1959.



DRESDEN EXPERIENCE enlarges General Electric's ability to predict schedules and costs.



after Dresden...acceleration

General Electric's Atomic Acceleration Program can realize the potential for low total energy costs demonstrated at Dresden

Acceleration to competitive nuclear power is necessary for national security and world leadership, technical and ideological. General Electric's Atomic Acceleration Program—a major effort in developing boiling water reactors in depth—promises the fastest realization of that goal, at minimum cost and least technological and financial risk. This industry-wide program complements government objectives and is designed to assist industry prepare for broad scale use of atomic power. General Electric will continue to investigate other promising reactor types.

The Dresden reactor—in the First Generation Phase of the program—will speed realization of the lower total energy cost potential of boiling water reactors. Immediate implementation of the Developmental Phase is necessary with these reactors planned to improve and test specific combinations of boiling reactor technology:

NCB-2 The **NATURAL-CIRCULATION BOILER** reactor, rated at 50 mw(e), has been committed by Pacific Gas & Electric Co. for the Humboldt Bay station and will stress extreme simplification and lowered costs.

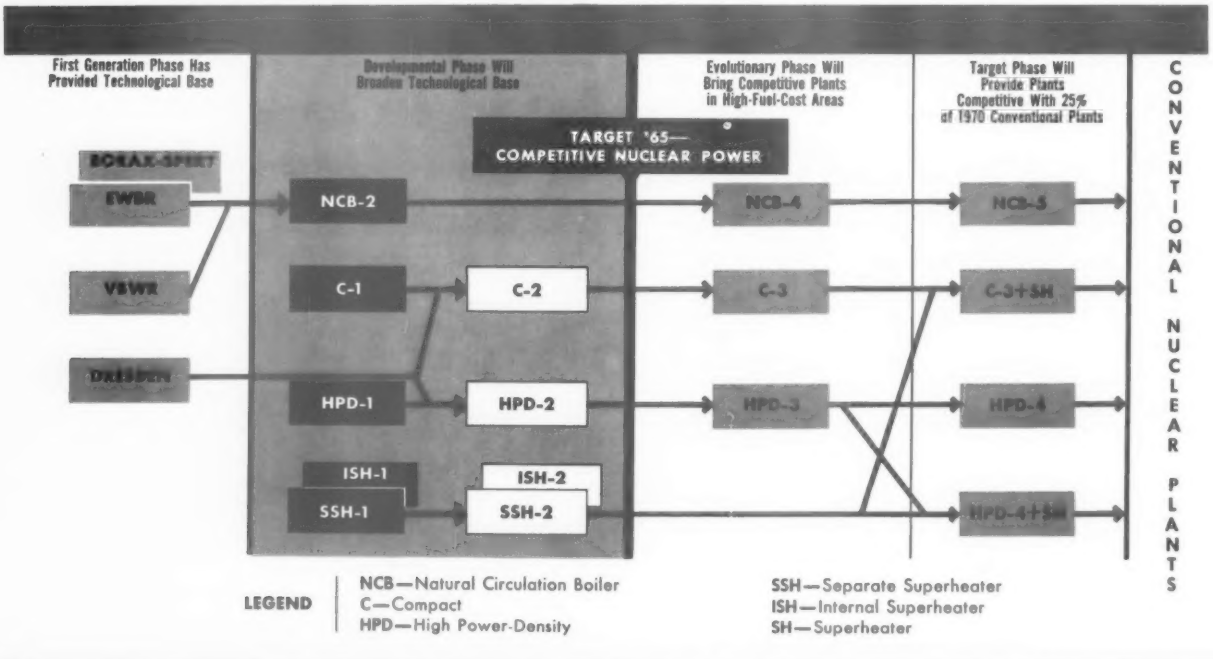
C-1 A **COMPACT** reactor, rated at 10-25 mw(e), is required to develop optimum design and construction simplicity for forced-circulation plants.

HPD-1 A **HIGH POWER-DENSITY** reactor, rated at 25-50 mw(e), is required to test the limits of power density and provide full-scale proving of high-power-density fuel.

SSH-1 or ISH-1 A **SEPARATE SUPERHEATER** or **INTERNAL SUPERHEATER,** rated at 10-100 mw(e), is required to evaluate operation and maintenance characteristics, extend nuclear superheat technology.

FOR INFORMATION on participation in this program, contact your nearest General Electric Apparatus Sales Office or write: Atomic Power Equipment Department, 2151 South First Street, San Jose, California. Publications GED-3750, "How to Implement Nuclear Power Acceleration" and GER-1574, "Operation Sunrise," provide more detailed discussion of the program, are obtainable by writing Section 192–14, General Electric Co., Schenectady 5, N. Y.

THE COMPLETE ACCELERATION PLAN FOR COMPETITIVE NUCLEAR POWER



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Promising Rookie

a report by LINDSAY

Brought out of obscurity several years ago because of its exceptional promise, newcomer thorium is slated to achieve importance as a fertile material along with the veteran, uranium. Actually, some of its properties have led several sage talent scouts to predict that thorium will outshine uranium as a fertile material long before the latter has passed its prime.

Such predictions are based not so much on the properties of thorium, as on those of the fuel produced as a result of its irradiation. The fact that U^{233} has a neutron yield considerably higher than that of either U^{235} or Pu^{239} makes possible the operation of reactors using thorium for the fertile material at conversion ratios close to, if not exceeding, 1.0.

This permits substantial neutron economies due to the need for less reactivity control. It decreases the need for so many control rods and housings; and, of course, it decreases fuel burnup costs measurably.

CAN GO THE DISTANCE

Assuming that fuel elements capable of withstanding the radiation damage can be produced, thorium also opens the way for consideration of fuel elements which could operate for 20,000-30,000 MWD/T. Even longer reactivity lifetimes could be anticipated if conversion ratios approximating 1.0 could actually be achieved.

As with all rookies, thorium has some unanticipated problems associated with its use. U^{232}, a by-product of thorium irradiation, decays, through Th^{228}, to a series of daughters which results in both the fuel and fertile material being radioactive. When compared with the use of clean, enriched uranium, this appears to be a serious disadvantage. Yet, when compared with the prospect of recycling the Pu and re-enriching the uranium which would come from uranium plants, the problems of dealing with the thorium cycle appear to be little if any more difficult.

Some fuel managers have been clever in planning fuel cycles using natural and slightly enriched uranium and if these prove to be real winners it would make sense to go along with them. Actually, some studies show that almost competitive nuclear power can be achieved by use of natural and very slightly enriched uranium, based on relatively short fuel lifetimes and considerable fuel juggling . . . like playing games with three pitchers, each of whom pitches three innings.

But is all this really necessary? The problems associated with the use of thorium are finite. The list of advantages and the promise are impressive. A little work and a lot of development could prove out thorium as the optimum fertile material for most reactors. Admittedly, considerable effort will be required to develop this youngster fully, but . . . *this is no time to send our bonus baby back to the minors.*

Actually, of course, thorium is no "rookie." We at Lindsay have been working with thorium compounds for nearly fifty years for a variety of industrial applications. We have ample production to meet any anticipated requirements and can supply to qualified people a considerable amount of data on thorium as a nuclear fuel.

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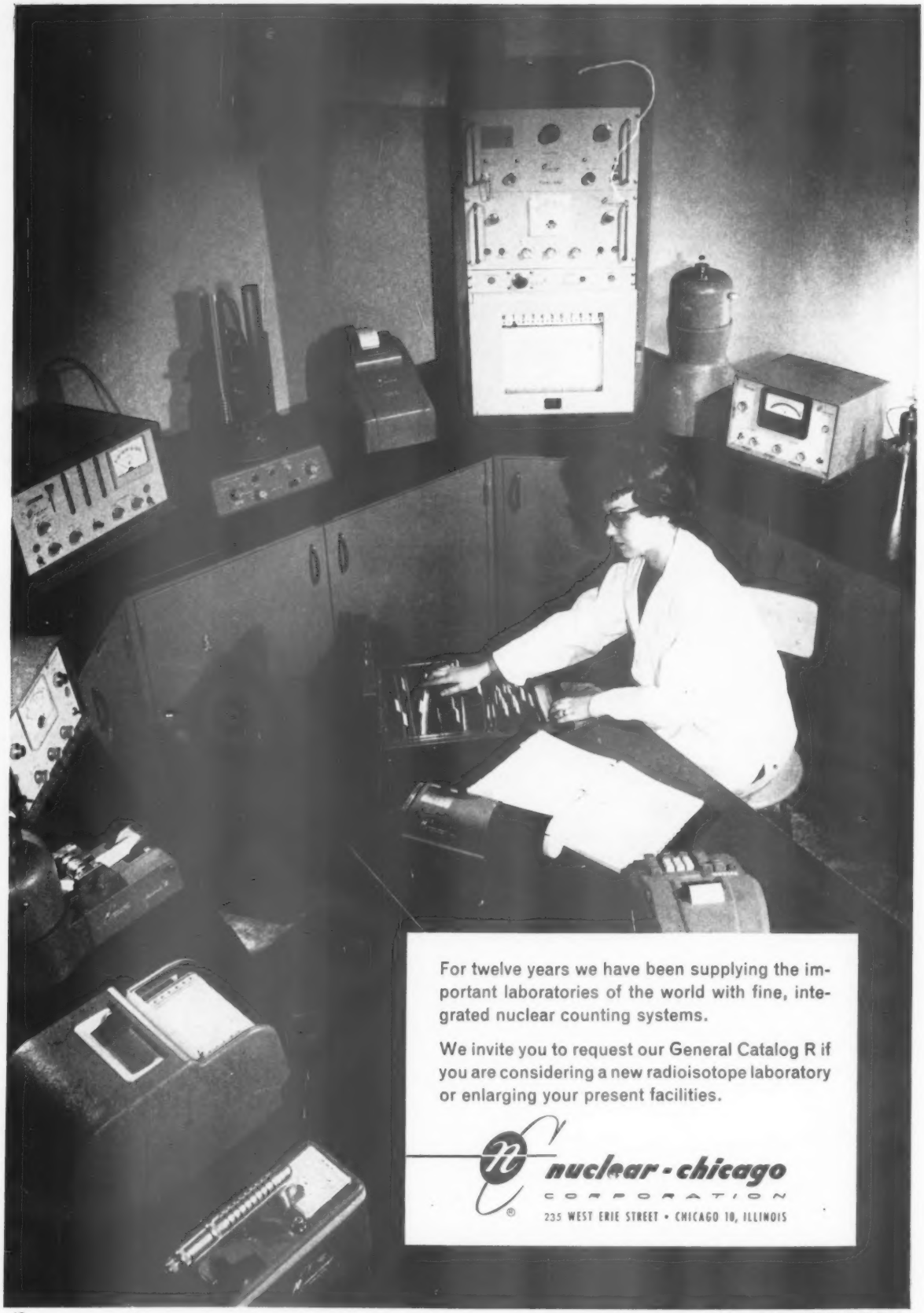
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CORPORATION
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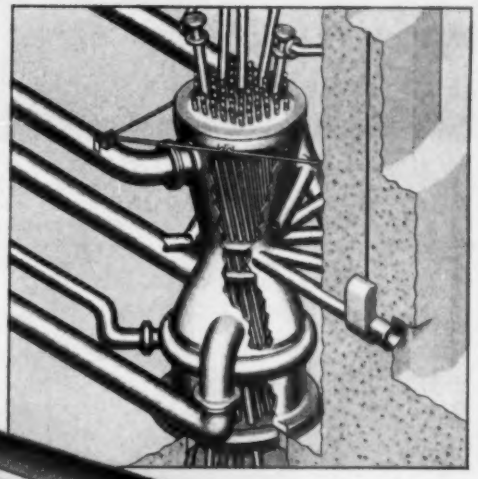
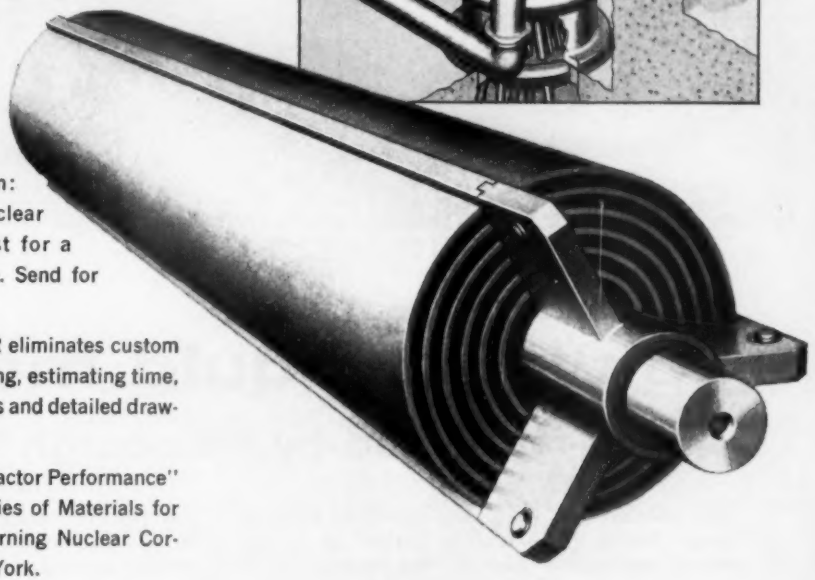
Europe's Highest-fluxed Reactor will be

FUELED by SYLCOR

The Belgian Engineering and Test Reactor, now under construction at Centre d'Etudes pour les Application de l'Energie Nucleaire at Mol, Belgium, is a notable example of joint American-European attainments in the field of nuclear technology. The plant will be of unique and advanced design by Nuclear Development Corporation of America. Fuel elements will be produced under the SYLCOR "Package Fuel" plan with substantial economies to the Belgian government.

The new reactor, designated METR, will have an ultimate epithermal flux density as high as 2.4 x 10^{15} n/cm²/sec, corresponding with a thermal output of 50 megawatts. The SYLCOR fuel elements consist of six concentric tubes of 90% enriched uranium-aluminum alloy clad in aluminum. 20 such tubes will fuel the reactor; three core loadings are being supplied. The elements must meet rigid dimensional tolerances both as to size and symmetry of tubes and water gaps and have been flow-tested at 35 feet per second.





Two recent SYLCOR developments warrant your study in designing or fueling nuclear power plants:

(1) The SYLCOR "Package Fuel" Plan: You obtain your allocation for nuclear material . . . SYLCOR does the rest for a fixed price which is the total charge. Send for information.

(2) Standard Fuel Elements: SYLCOR eliminates custom design, special drafting and engineering, estimating time, special tooling and testing. Data sheets and detailed drawings on four types available.

Write for "Nuclear Fuels: Key to Reactor Performance" and "Physical & Engineering Properties of Materials for Nuclear Fuel Elements." Sylvania-Corning Nuclear Corporation, Bayside, Long Island, New York.

SYLCOR

SYLVANIA–CORNING NUCLEAR CORP.

Above: After welding together two sections of volute (one shown below) the areas adjacent to the welds are high frequency induction heated to 1950°F. prior to quenching.

Below: Section of volute which is fabricated entirely of Stainless Steel Type 316, for handling of liquid metal at 1250°F.

Stainless Steel Volute for liquid metal...

fabricated by Pittsburgh Piping

This stainless steel volute was fabricated by Pittsburgh Piping for a leading builder of nuclear energy equipment. The job was awarded to us because we have highly specialized facilities, plus broad experience in nucleonic piping work. This experience began when we fabricated piping for the Nautilus and for the main coolant lines of the Shippingport atomic-powered central station. It has been extended and expanded through the work we have been doing for the atomic-powered submarine and surface vessels now being built, and for scores of government and industrial nuclear energy installations. Use this experience on your next nucleonic piping job. Our representative will call on request, or we will be glad to have you visit our plant.

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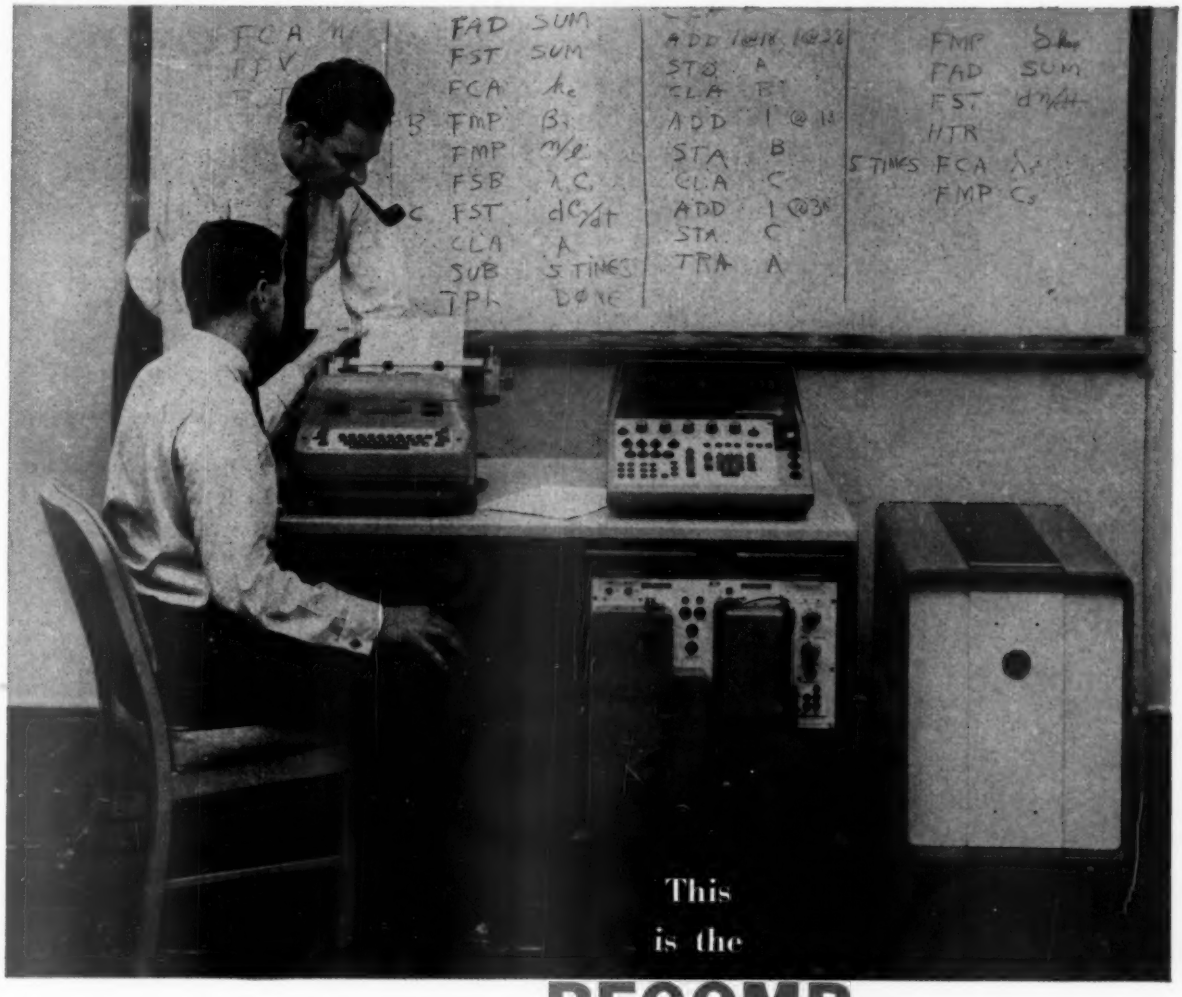

RECOMP

digital computer

It has a storage capacity of 8,000 instructions ... and it's low-priced

No problem is too complex to tackle with Recomp—and you can afford to put it wherever it's needed to break up computer-time bottlenecks. It's easy to use, too; engineers quickly learn to program their own problems. *Other Recomp features:* a command structure of 49 arithmetical and logical commands—including 9 built-in floating point commands ... standardized teletype tape configuration ... all-transistorized ... 400-character-a-second input ... electronic console that puts all basic controls within fingertip reach ... simplified coding. Recomp gives you far more capacity, versatility, and trouble-free service for your money. It's available for sale or lease. *There's no extra equipment to buy ... no cost of installation.* Please write for complete literature. Industrial Products Division, Autonetics, Dept. 27 3584 Wilshire Boulevard, Los Angeles 5, California.

This engineer learned to program Recomp in two days

Digital computers by Autonetics

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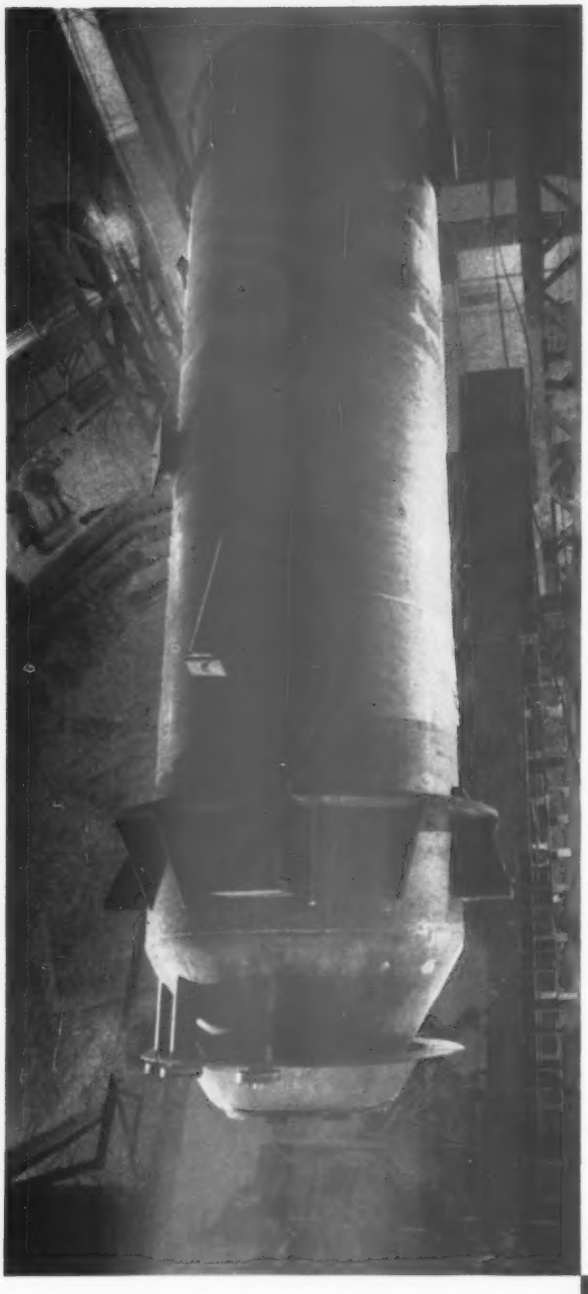

PACECO stainless steel reactor vessel, heart of the new Westinghouse Testing Reactor, is pictured during installation at Waltz Mill, Pennsylvania. The new vessel, 30′ long, 7′10″ in diameter, weighing 84 tons, has a head section which is the largest stainless steel casting ever produced. The WTR, a privately owned facility for use by government, industry, universities, and scientific groups, is a thermal neutron reactor, cooled and moderated by light water. Power output, about 20,000 kw heat equivalent; vessel is designed for 110 P.S.I.G. at 135° F.

PACECO's nuclear equipment experience is your insurance of exacting performance at low cost

PACECO has designed and built equipment for almost every project of the AEC during the past 10 years, as well as several privately financed projects. Let PACECO work for you! Engineering consultation with PACECO at the planning stage may *sharply lower your initial cost.*

PACECO *has supplied atomic projects with*

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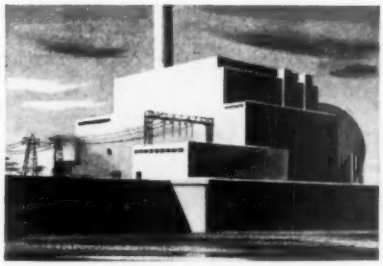
In nuclear submarines...



In atomic power plants...

Darling 14" stainless steel gate valve of the type used on nuclear submarines.

...there's good reason to specify

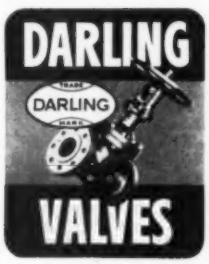
DARLING STAINLESS STEEL VALVES

Today, Darling gate valves are in service on the Skipjack and other submarines in the U. S. Navy's mighty new nuclear fleet. Here's proof that Darling has the design and manufacturing know-how to meet exacting Navy specifications for valves used in its nuclear power plants.

Wherever you need valves for any type of nuclear service... power generation, atomic-powered propulsion or flow control of radioactive fluids... consult Darling. We offer you both the engineering experience and precision manufacturing facilities to meet your most exacting needs.

In Darling gate valves, you also get the advantage of our *exclusive revolving double disc parallel seat* feature... which assures positive sealing and ease of operation at all times.

Write or phone us about your valve requirements for nuclear power plants. Or we'll gladly have a Darling sales engineer call.



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Manufactured in Canada by Sandilands Valve Manufacturing Company, Limited, Galt 19, Ontario

Northwest corner of the Brookhaven Hot-Laboratory...

What is going on here that makes Monel a "must" for every vessel, pipe and pump?

You are looking at a pilot plant designed to continuously recover $2,000 worth of natural uranium per day from "spent" nuclear fuel elements.

In the process, stripped fuel slugs are dissolved in liquid bromine trifluoride. The solvent reacts with the uranium to form uranium hexafluoride. An evaporator removes plutonium tetrafluoride and other non-volatile fluorides. The condensed vapor is then distilled to obtain BrF_3, bottoms and tops high in UF_6. The UF_6 is recovered from the reflux. BrF_5 is added to the dissolution mixture to react with the Br_2 in order to regenerate BrF_3. The heat of dissolution is removed in an external water cooled heat exchanger. Sealless Pumps circulate process liquid

Monel* nickel-copper alloy was selected as the material of construction on the basis of its high temperature strength and because corrosion studies conducted at Argonne and Brookhaven National Laboratory showed negligible attack in BrF_3 at 125° C. Monel was used for vessels, piping, valves, gaskets and pumps. "K" Monel* age-hardenable nickel-copper alloy, and "S"* Monel hard-grade nickel-copper cast alloy were used for special parts. A sintered nickel filter was used to remove particles over 7 microns in size.

Are fluorine or fluorides causing corrosion troubles in your plant? Tell us about it. We'll be glad to lend our experience in helping solve many similar problems. And, for more information, write for a free copy of "Handling Fluorine and Fluorine Compounds With Inco Nickel Alloys".

*Registered trademark

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INCO NICKEL ALLOYS

DIRECT CONVERSION

During the last year, direct conversion of heat into electric power has changed at a phenomenal rate from the status of a laboratory vision to that of working hardware. The two main approaches—thermionic and thermoelectric—are similar in a sense: in the first, a current flows between two electrodes when they are held at different temperatures; in the second, electric power is produced when a suitable material is subjected to temperature gradient. Both approaches are suited for use with nuclear-energy sources. In this issue NUCLEONICS covers thermionic converters for nuclear power—the fundamentals below and the recent Los Alamos experiments on p. 54. Future reports on direct conversion will cover thermoelectric devices.

Thermionic Converters

Thermionic cells built from existing materials will soon be converting thermal energy into electricity with very good efficiency at high temperatures; combined with nuclear fuels, they offer exciting possibilities

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THERMIONIC CONVERSION, a method of converting heat directly into electricity, promises to have the highest efficiency of all the direct-conversion schemes. Where thermoelectric converters, for example, must strain to get to thermal efficiencies of 10%, thermionic converters look forward to efficiencies as high as 25–30%—almost the same as the efficiencies of present-day central power stations. But this excellent performance requires a heat source that can operate at quite high temperatures (around 1,100° C, or 2,000° F).

For nuclear heat sources (such as reactor fuel elements) this temperature level is about double the upper limit of current operating experience; however, there is good reason to believe that fuel temperatures such as these will eventually prove feasible. In fact, some reactor concepts under development today [e.g., Project Rover (NU, July '58, p. 70)] are planning for much higher temperatures.

In other respects, nuclear energy and thermionic conversion go well together; for instance, gamma radiation from the nuclear-energy source may be useful in counteracting space-charge effects in the converter. And we already can suggest materials that have good thermionic properties and stand up under high temperatures and intense radiation fluxes. Thermionic converters made from these materials could operate at power densities close to those found in today's power reactors. As work on thermionic conversion continues, we can expect to develop such things as packaged nuclear power supplies that will operate without moving parts in remote areas or in space vehicles (see box, p. 51). Perhaps more important, future power reactors may combine thermionic conversion with the conventional turbogenerator system of conversion to achieve thermal efficiencies as high as 50–60%.

Thermionic Principle

In its simplest form (*1*) a thermionic energy converter consists of two electrodes in a vacuum. One electrode (the emitter) is kept hot enough to emit electrons thermionically while the other electrode (the collector) is kept cool. Electrons boiled off from the

emitter flow to the collector, out through the external load and back to the emitter. The arrangement of a thermionic unit is analogous to that of conventional *thermoelectric* devices (*2*): the emitter corresponds to the hot junction of the thermoelement, the collector to the cold junction, and the vacuum to the thermoelectric material between the two junctions.

This comparison helps us understand why thermionic converters have relatively high conversion efficiencies. Thermoelements have *low* efficiencies (for conversion of thermal energy to electricity) primarily because of heat flow through the thermoelement itself —the thermoelectric material acts as a "thermal short circuit" between the hot and cold junctions. Hence the ideal thermoelectric material should have high electrical conductivity and low thermal conductivity.

Now the thermal conductivity of the vacuum between the two thermionic electrodes is practically zero. True, heat is still transferred between the two electrodes by radiation but this is much less important than the conduction of heat in a thermoelectric solid (at low temperatures, at least) and can be reduced by proper shielding. In addition, the vacuum space can be made an excellent conductor of electricity. (Space-charge effects in the vacuum tend to limit current flow; however, these effects can be overcome by methods described below.) Thus if we think of a thermionic converter as a thermoelectric element, we see that the vacuum space has properties that approach those of the ideal thermoelectric material.

Electrode Work Functions

In principle, any diode will work as a thermionic converter (*3*); some of the electrons emitted from the hot electrode will always have enough energy to cross the retarding potential to the collector. However, to obtain highest conversion efficiencies (*4*, *5*) (ratio of electric power developed to heat put in), a thermionic energy converter must take advantage of the difference in "contact potential" between the two electrodes. For an electron tube the contact-potential difference can be defined as the difference between the surface work functions of the emitter and the collector. Throughout the rest of this paper we will assume that this potential difference is larger than the average kinetic energy of the emitted electrons (both expressed in electron volts). When this is true, the converter efficiency will be a maximum (maximum electrical power delivered to the external load) when the voltage across the load is exactly equal to the contact-potential difference.

To understand this consider Figure 1, which gives the potential-energy diagram for electrons under these conditions. Here ϕ_1 is the work function of the emitter and ϕ_2 the work function of the collector. We assume that the external-load impedance R_L has the value $(\phi_1 - \phi_2)/I_2$ (where I_2 is the collector current) and that there are no space-charge effects in the interelectrode space. The potential in the interelectrode space is then constant as shown.

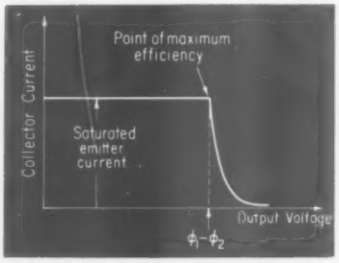


FIG. 1. VOLT-AMP CHARACTERISTIC of thermionic converter (theoretical)

Heating the emitter raises the potential energy of some electrons from the Fermi level in the emitter to beyond the top of the potential barrier at the emitter surface. Some of these electrons leave the emitter surface and flow to the collector. When they enter the collector, the electrons lose ϕ_2 volts of potential energy. (This energy appears as heat in the collector and must be removed by cooling.) The remaining potential energy of the electrons—the contact potential difference $\phi_1 - \phi_2$—is delivered directly to the load R_L as electrical energy.

Electrically the converter behaves as a constant-current generator for load impedances $R_L \leq (\phi_1 - \phi_2)/I_2$. With no space charge, the collector current is just equal to the saturated emission current of the emitter given by the Richardson equation. For load impedances $R_L > (\phi_1 - \phi_2)/I_2$ the collector current drops off exponentially as shown in Fig. 2.

Converter Efficiency

When the interelectrode space has no net space charge, the maximum conversion efficiency of a thermionic energy converter can be written

$$\eta_{max} = \frac{\phi_1 - \phi_2}{\phi_2 + P_L/I_2} \qquad (1)$$

where P_L is the sum of heat losses from the emitter. For this expression to hold, the electron emission from the emitter must exceed the electron emission from the collector; in terms of the Richardson equation

$$T_1^2 e^{-\frac{e\phi_1}{kT_1}} > T_2^2 e^{-\frac{e\phi_2}{kT_2}} \qquad (2)$$

where we assume thermal-emission constants are the same for the two surfaces. The predominant part of the heat-loss factor P_L is the heat radiated from the hot emitter. In addition heat also flows by conduction through the leads connecting the emitter to the external load but this can be minimized with leads of the proper dimensions. Leads of small diameter reduce the heat loss at the expense of lowering the voltage output because of the higher electrical resistance. Calculations show that for the optimum dimension these losses are of second order in most instances. Another source of heat loss is the $2kT_1/e$ units of kinetic energy dissipated by each electron on the average when it strikes the collector.* But this loss factor also is of second order. Therefore we can with good accuracy assume that P_L consists wholly of radiation losses. For a geometrical arrangement that has perfect shielding of the heat source and emitter (except for the emitter area facing the collector), the heat loss per unit area is

$$P_L \cong \sigma(T_1^4 - T_2^4)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)^{-1} \qquad (3)$$

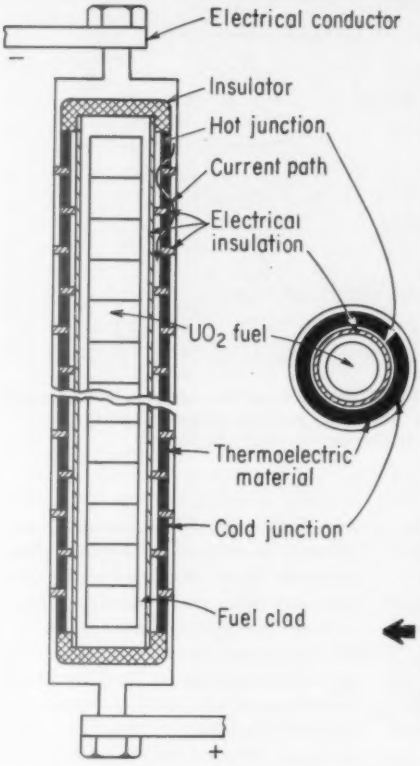
where

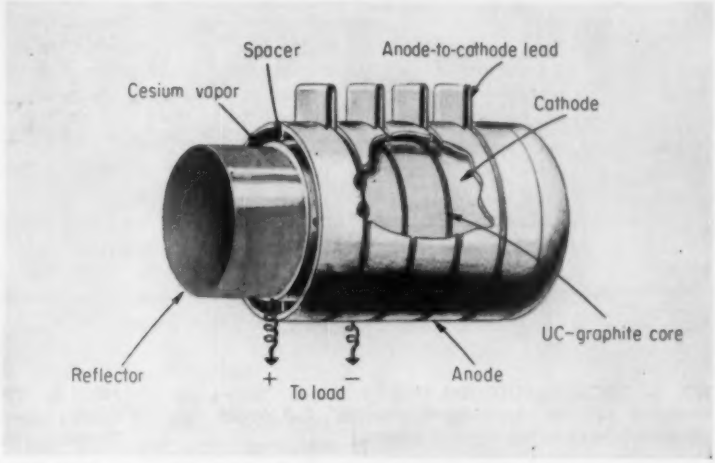
σ = Stefan-Boltzmann constant
ϵ_1 = thermal emissivity of the emitter
ϵ_2 = thermal emissivity of the collector

If we substitute Eq. 3 into Eq. 1 and set the net current I_2 equal to the saturated emission current from the emitter, the efficiency becomes

* If this loss factor alone is included in Eq. 1 then Eq. 2 leads to the familiar relation $\eta < \eta_{Carnot} = 1 - T_2/T_1$.

Direct Conversion Applied to Nuclear Reactors





THERMIONIC POWER SOURCE (above) proposed by Martin for outer space vehicles is solid cylinder of UC embedded in graphite matrix with thoriated-tungsten cathodes oxygenated-tungsten anodes wrapped around circumference. Anode would double as waste-heat radiator. Unit would generate 27 kw(e) with efficiency of 9.7% and would weigh 1,400 lb. Reactor core would be 2-ft square cylinder; spacing between anode and cathode would be 0.100 in.

THERMOELECTRIC FUEL ELEMENT (left) conceived by Westinghouse is Yankee-type fuel rod (UO_2 with stainless-steel clad) surrounded with layer of mixed-valence thermoelectric materials. Alternate layers of n-type and p-type materials in vertical stack generate voltage in series. Element would convert 5% of fission heat into electricity; remainder would go to ordinary steam cycle.

Both thermionic and thermoelectric schemes can be combined with nuclear-reactor heat sources in a variety of applications. The thermoelectric fuel element and thermionic power source pictured above are examples. In general, the thermoelectric schemes have the advantage of being simpler and more rugged; they require no vacuum capsule or fancy plasma-generating device. On the other hand, thermionic converters are capable of a higher conversion efficiency.

Both are high-temperature devices with the thermionic temperature the higher of the two. For example, the mixed-valence compounds proposed as the thermoelectric materials for the fuel element above function at temperatures up to about 1,800° F. Together with a fuel center-line temperature limit of 4,500° F, this limit allows a coolant water temperature of 650° F if the thermoelectric material thickness is 0.020 in. In the thermionic source, the reactor would run at about 4,000° F at the center and 3,000° F at the cathode surface; the anode would be at 2,200° F.

Fuel-bearing materials, such as UC, appear to have useful thermionic properties on their own. The Los Alamos in-pile cell (p. 50) uses a ZrC-UC emitter while Livermore has recently announced that a converter with a ThC cathode and Ni anode has achieved 15% efficiency and electric power densities of 15 w/cm².

$$\eta = \left(1 - \frac{\phi_2}{\phi_1}\right)\left[1 + \frac{\sigma}{A_1}\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)^{-1}\frac{T_1^4 - T_2^4}{T_1^2}\,\phi_1^{-1}\exp\frac{e\phi_1}{kT_1}\right]^{-1} \quad (4)$$

where A_1 is the thermal-emission constant of the emitter.

Equation 4 shows how the conversion efficiency η depends on the material of the collector: A low work function ϕ_2 and (to lesser degree) a low thermal emissivity ϵ_2 favor high conversion efficiency. Equation 2 sets the theoretical lower limit on ϕ_2. Materials suitable as collectors are listed in Table 1; note that work functions as low as 0.7–1.0 volt are available.

The efficiency depends on the work function of the emitter ϕ_1 in a more complicated way because ϕ_1 occurs in the exponential. In general, however, the efficiency at first increases with increasing ϕ_1 (if $\phi_1 > \phi_2$ and the other quantities in Eq. 4 remain constant). η reaches a maximum for some value of ϕ_1 and then decreases for higher ϕ_1.

The efficiency varies almost exponentially with the emitter temperature T_1. This fact points up an important feature of the thermionic energy converter—it is a high-temperature device. With materials presently available, reasonably high efficiencies will call for heat-source temperatures in excess of 1,000° C. Table 1 lists some electron emitter materials that can operate in the temperature range 1,000–2,000° C. At still higher temperatures (2,000–3,000° C) refractory metals such as tantalum and tungsten may be used.

How thick the materials on the electrodes should be is not critical, apart from structural rigidity. Thicknesses of a few millimeters or less would probably be typical. Radiation damage in nuclear-energy converters will not likely be a problem because

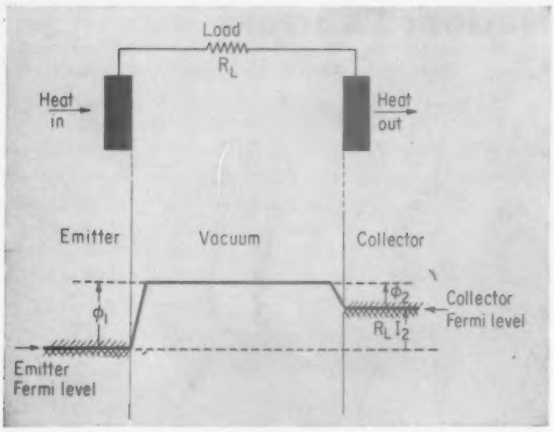


FIG. 2. ELECTRON-POTENTIAL ENERGY diagram for vacuum thermionic cell (no interelectrode plasma). Cell output $R_L I_2$ equals difference between work functions

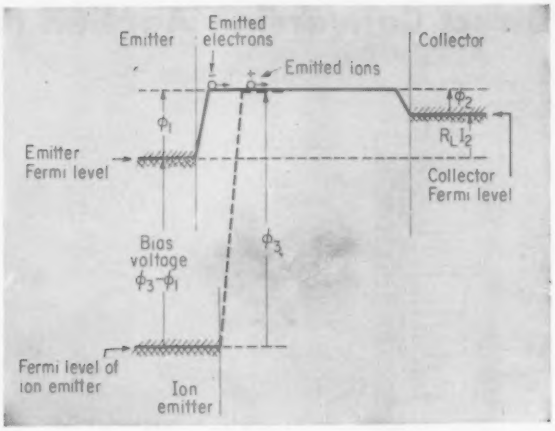


FIG. 3. ION-EMITTER BIAS makes positive-ion potential (dotted curve) equal to electron potential (solid curve) in thermionic cell employing interelectrode plasma

the materials suggested are not single-crystal structures.

Reducing Space Charge

The collective charge of the electrons moving in the space between the two electrodes tends to repel other electrons emitted from the electrodes. Unless this charge is neutralized in some way, it will eventually limit the current flow from the emitter to the collector.

Several ways to reduce space-charge effects have been suggested (*4, 6*). Perhaps the most promising for a relatively large device is to introduce positive ions in the interelectrode space. The positive ions would be trapped in the negative-potential trough of the electron space charge until the potential becomes uniform (as shown in Fig. 1). At this point the interelectrode space contains equal numbers of electrons and ions per unit volume and, in effect, is occupied by a gaseous plasma. Because a plasma has ideal thermoelectric properties—high electrical conductivity but low thermal conductivity—and no space-charge effects, we can regard such a gaseous plasma as a thermoelectric medium superior to either solid materials or a vacuum.

We will briefly discuss two methods of generating the plasma. One is called plasma synthesis (*4*) and the other, useful for converters with nuclear or radioactive heat sources, depends on ionization by the gamma radiation. In plasma synthesis the electrons and positive ions are generated separately and then brought together in the interelectrode space. The electrons making up the plasma are of course the thermionic electrons from the emitter. The ions are best supplied from a source that uses contact (or resonance) ionization. In this process, gaseous atoms with low ionization potentials (such as cesium and rubidium) are ionized with a yield close to 1 when they strike a hot surface with a high work function (such as tungsten). If we fill the diode space with a suitable gas (e.g. 10^{-3}–1 mm Hg of cesium vapor) and provide a hot high-work-function surface, positive ions will be continuously generated and injected into the electron space charge to form a neutral plasma.

When the work function of the electron emitter is of the order of 3.9 v or higher (which corresponds to a heat-source temperature in excess of 2,000° C) the electron-emitting surface can also serve as an ion emitter (*4*). When the work function of the electron emitter is low, the situation becomes more complicated since a separate ion-emitting electrode must be introduced. This electrode must be in thermal contact with the heat source but would have to have an electrical bias with respect to the other electrodes. The bias should be just enough to make the top of the potential barrier of the high-work-function surface level with the top of the barrier for the emitter (see Fig. 3).

TABLE 1—Thermionic Converter Materials

Material	*Work function (volts)*	*Temperature range (° C)*
Collectors	ϕ_2	
BaO/SrO on Ni	1	
Cs on AgO	0.75	
Cs on WO	0.71	
Emitters	ϕ_1	T_1
Ba-impregnated W	1.7	900–1,200
Th on W	2.55	1,800–2,000
Cs on W	1.7	1,400–1,600

The ion current required to neutralize the space charge is approximately equal to $(m_e/m_p)^{1/2}$ times the electron current I_2. (m_e and m_p are the electron and ion masses respectively.) This means that with cesium ions, for instance, each ion during its life would allow passage of about 500 electrons from emitter to collector.

The second method of plasma generation uses the high gamma-ray intensity from the nuclear heat source that would power the converter. The gamma rays would create electron-ion pairs directly in a gas filling the interelectrode space. The electrons generated would travel swiftly to the nearest electrode but the ions would remain trapped in the negative potential trough caused by electrons streaming from the emitter. The positive-ion density will continue to build up and flatten out the potential trough until the ion leakage out of the trap equals the ion-generation rate. (This will happen when the potential is still slightly negative.)

Rough calculations assuming typical reactor gamma fluxes ($\sim 10^8$ roentgens per hour) and a xenon gas environment

(at 1 mm Hg) show that the ion-trapping must be effective enough for each ion to allow the passage of about 500,000 electrons from emitter to collector. A final evaluation of this method of plasma generation depends on further experimental work.

In space-charge cancellation with positive ions, the spacing between electron emitter and collector is not critical. However, to minimize back scattering of electrons and volume recombination of ions, the spacing should not be much larger than the mean free path for electrons in the neutral gas. For plasma synthesis with cesium ions, this would mean an interelectrode spacing of about 1 mm.

To summarize the present status of the space-charge problem, we can say that an adequate solution exists for converters with heat-source temperatures above 2,000° C. For lower temperatures, the problem has not been solved. Undoubtedly this gap will be bridged both by extending reactor techniques to the extreme high-temperature region and by further progress in thermionic energy conversion.

Voltage Step-up

A second problem of thermionic converters is that they are intrinsically low-voltage high-current d-c generators. A 1-kw power unit may, for example, deliver 1,000 amperes at 1 volt, requiring a load impedance of only 10^{-3} ohms. For most uses this load impedance is impractically low. Thus some method to step up the voltage is essential. One way is to connect many converter units in series; the total output voltage is then the sum of the individual unit voltages.

Another method—current modulation within the converter itself—would produce an a-c output voltage from the converters (connected in parallel) which could then be stepped up with a transformer. Since the thermionic converter is essentially a vacuum or gas-discharge tube, it can adopt the modulation techniques used in these fields. For instance, a small modulation signal on a grid placed between the emitter and collector would modulate the electron current through the converter and produce an a-c output voltage. A transformer with the correct turns ratio will then match the converter to any load impedance. Another method of modulation would be to switch the electron flow between several collectors by using very weak external magnetic fields. Finally, in converters that use plasma synthesis, the electron current can be modulated by modulating the ion-injection rate.

Practical Converter Design

We now want to imagine what an actual thermionic converter would look like, and try to say something about its performance. A convenient arrangement of the electrodes is an annular configuration (like the Martin version in the box on p. 51) in which the collector encloses the emitter and heat source. For a small power package the cylindrical heat source might be a radioactive isotope or the entire core of a small reactor. For a large power plant the annular unit would correspond to a typical fuel-element assembly (similar to the Westinghouse element in the box on p. 51).

For the emitter material we choose a porous tungsten body impregnated with a barium compound (ϕ_1 = 1.7 v), for the collector a nickel body with a thin coating of barium and strontium oxides (ϕ_2 = 1.0 v). We choose these materials primarily because their thermionic properties are well known; better materials may turn up in the future.

If we use published values (7) of the emission-current density vs. emitter temperature and describe the emitter-collector heat loss by Eq. 3, then we can calculate the electrical and thermal power densities and the thermal efficiency of the converter for various emitter temperatures. The results are summarized in Table 2. (We assumed $\epsilon_1 = \epsilon_2 = \frac{1}{5}$ and a collector temperature of 500° C; the latter choice makes Eq. 3 valid over the range of emitter temperatures considered.)

The performance figures shown in Table 2 are probably typical of the thermionic power converters that may be available in the not-too-distant future. The high-temperature requirement (1,100° C for efficiencies of 25–30%) will be the main obstacle in using thermionic conversion with nuclear reactors. However, the thermionic power densities shown in Table 2 are in the same ballpark as the power densities of present-day power reactors; future developments should solve the engineering problems of high-temperature operation.

In a practical direct-conversion power reactor the heat removed (at 500° C) by the collector coolant could in turn be used to make steam for a turbogenerator. In this way, a plant using both the thermionic and conventional methods in series to convert nuclear heat into electricity might reach an overall thermal efficiency as high as 50–60%.

TABLE 2—Thermionic Converter Performance*

Emitter temperature (°C)	*Current density* (amp/cm²)	*Heat-power input to emitter* (watts/cm²)	*Heat power removed from collector* (watts/cm²)	*Electrical-power output* (watts/cm²)	*Efficiency* = η (%)
900	0.1	2.32	2.25	0.07	3.02
936	0.5	3.26	2.91	0.35	10.7
965	1.2	4.68	3.84	0.84	17.9
1,020	2.6	7.92	5.96	1.96	24.7
1,070	5.2	12.52	8.88	3.64	29.1
1,130	9	19.69	13.39	6.3	32.0

* For emitter of Ba-impregnated W and collector of BaO/SrO on Ni.

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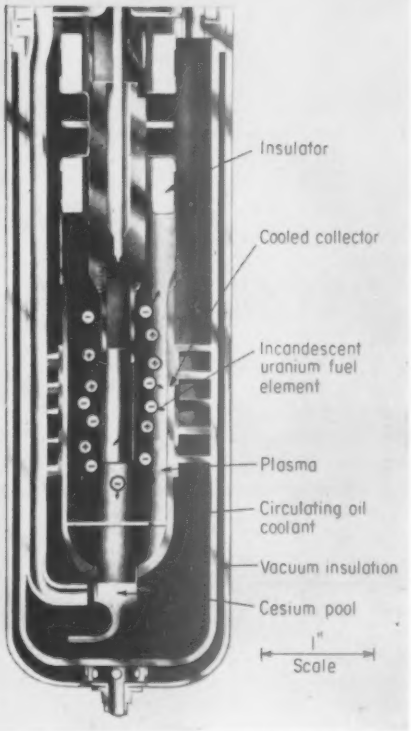

FIG. 1. FISSION-POWERED thermionic test cell operated at Los Alamos. Emitter element is solid solution of ZrC : UC; collector is stainless

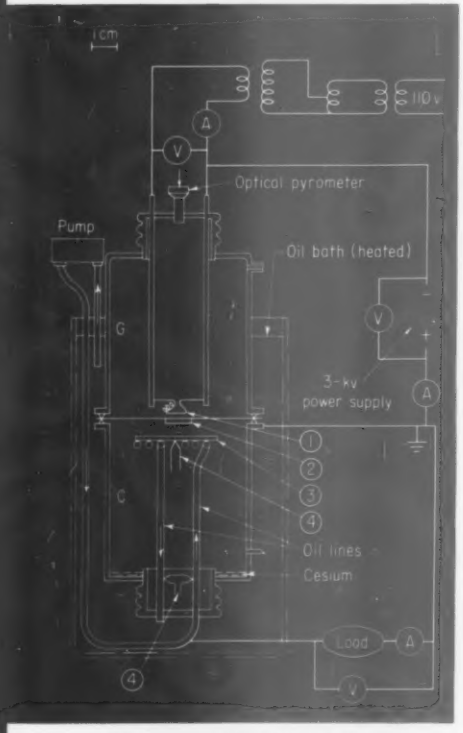

FIG. 2. ELECTRICALLY HEATED cell uses electron-gun beam from filament (1) to heat emitter plate (2). Thermocouples (4) record temperatures of collector (3) and oil coolant

DIRECT CONVERSION

Los Alamos Plasma Thermocouple

By G. M. GROVER
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IN OUR EXPERIMENTS at Los Alamos on thermionic conversion, we have recently succeeded in converting heat from fissioning material directly into electricity. Our "plasma thermocouple" (see Fig. 1) operating in the core of a Los Alamos research reactor generated closed-circuit currents as high as 35 amps and an open-circuit voltage of 3.8 volts, indicating a power output through a matched load of the order of 30 watts.

This experiment represents for us a major step toward our goal of developing nuclear-energy sources for outer-space propulsion under Los Alamos's Project Rover (NU, July '58, 62). Our in-pile thermionic cell could, for instance, turn out to be the ancestor of a nuclear-electric ion-propulsion device for inter-orbit missions. In the past, the power per unit weight of such systems has always been limited by the "heat dump" temperature (which in turn determines the rate at which waste heat is radiated away). In a thermionic device, the sink temperature (the temperature of the cold junction) can be very high. We have operated a cell 2,700° K at the hot junction and 1,700° K at the cold.

Thermionic Experiments

For several years a small effort at Los Alamos has been devoted to the study of thermionic cells to convert fission heat directly to electricity. Along with other groups (*1–4*), we have become interested in thermionic emission for this purpose; our attention has centered on thermionic cells in which an ionized cesium gas fills the space between the anode and cathode. The path through the cesium plasma together with the external leads to the cell electrodes forms a closed electrical circuit. As first pointed out to us by John Reitz (Case Inst. of Tech.) and H. Lewis (Univ. of Wisconsin), a circuit of this kind can be thought of as a "plasma thermocouple." The interface between the emitter electrode and the cesium gas corresponds to the hot junction, while the interface between the collector and the cesium gas represents the cold junction. We find that the thermocouple theory agrees reasonably well with our experimental observations at high cesium pressures.

In the ideal experimental cell, the method of energy supply to the hot electrode should be free of extraneous electromagnetic effects that would mask those produced by the thermoelectric process. Three methods of electrical heating have been used by various groups: direct $I \cdot R$ heating of the emitter, pulsed $I \cdot R$ heating with measurement made during the interval between pulses, and indirect heating. Of these, indirect heating is least bothered by extraneous effects; hence at Los Alamos we have used two methods of indirect heating. The first, indirect heating with electron bombardment, has proved very informative; the second, fission heat from a uranium element in neutron flux, recently provided the first successful demonstration of direct nuclear-power conversion.

Electron-Gun Cell

In the experiments heated with elec-

tricity (see Fig. 2), a 1–3-kev electron gun (chamber G) bombards a 2-cm² area of a metal partition that seals off the top of the thermionic cell (chamber C). This spot, which receives an electron bombardment of 0.1–0.7 amp, forms the hot-emitter surface. Since the emitter surface is on the opposite side of the target surface, the cell enclosure makes a good electrostatic shield against the gun fields; as a result, extraneous electric and magnetic fields are reduced to negligible values.

The collector electrode is insulated from the chamber walls and is cooled by oil circulating from the bath that surrounds the chamber. The oil cooling system provides a rough measurement of the heat flow from the emitter to the collector. The silicone oil bath can be thermostatically controlled at temperatures up to 300° C, which gives a cesium pressure range from 10^{-6} to 1 mm Hg.

The emitter-electrode surface is generally Ta. The collector surface is Cu.

Fig. 3 shows the open-circuit voltage as a function of the emitter-plate temperature for various Cs pressures. Comparison of curve *a* with curve *b* indicates a rather large effect for even the smallest amount of Cs. As the oil-bath temperature is raised one obtains the curves labeled *c* and *d*.

The magnitude of the voltages observed in curves *c* and *d* agrees reasonably well with the ordinary thermodynamic treatment of a thermocouple. As predicted by Wilson (*5*) the thermoelectric power of the plasma (a non-degenerate electron gas) is very much larger than those of metal conductors.

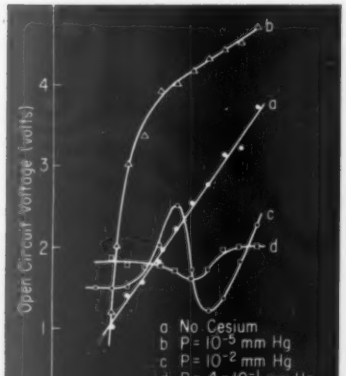

FIG. 3. OPEN-CIRCUIT VOLTAGE vs. emitter temperature for various cesium atmospheres in electrically heated cell

Since the output current and voltage are functions of the load resistance the proper choice of load maximizes the power output of the cell. The maximum value depends on such parameters as the Cs pressure and emitter temperature and material. To date our highest emitter power has been 30 watts/cm². The short-circuit current is also a function of the three parameters; our maximum value is 62 amps/cm² of emitter area. If we define the efficiency in terms of the heat received by the collector (as measured by the oil flow rate and the difference thermocouple shown in Fig. 1) then we have obtained values of about 15%.

In-Pile Cell

Figure 1 shows a cross-section of the in-pile test cell. The emitter rod is made of a solid solution of ZrC:UC with the U of the lower half of the rod enriched to 94%. This rod is fused to a tantalum support element that threads into a copper mounting. The collector is stainless steel with copper cooling fins.

On assembly, the container was evacuated, the cesium introduced and the container sealed off. Hot oil circulated between the collector and the outer dewar walls controlled the cesium pressure. The outer dewar walls allowed the assembly to be immersed in the cool (37° C) water of the reactor without seriously disturbing the temperature distribution within the cell.

The cell as shown in Fig. 1 was attached to a 20-ft-long tube that contained the oil lines and instrumentation leads to the cell. A remote operating switch installed in the tube just above the cell opened or closed the circuit to permit alternate voltage and current measurements. Malfunction of the third position of the switch prevented operation of the cell at near optimum power output.

The cell assembly was inserted into a central fuel-element position in the 5-Mw(th) tank-type reactor at the Omega West site at Los Alamos. Here it received the maximum neutron flux available in this reactor (about 10^{13} at the fuel-pin surface).

The reactor was brought up to the full power of 5 Mw in ½-Mw steps. The short-circuit current was monitored continuously with occasional

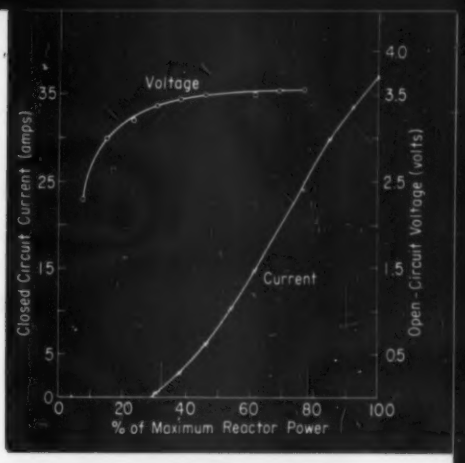

FIG. 4. VOLTAGE AND CURRENT generated in in-pile cell vs. test reactor power

open-circuit voltage measurements. The reactor was then operated for five hours at full power. During this period, the open-circuit voltage of the cell showed essentially no variation while the short-circuit current dropped off about 20% during the first hour or so. After a normal shutdown of the reactor, the system was left for two days. Again the reactor was brought to full power and operated for another five hours. The cell's open-circuit voltage and the short-circuit current were the same as before the shutdown and showed little variation during the second five hours of operation.

In Fig. 4 we have plotted the open-circuit voltage and short-circuit current as a function of reactor power. Because of the switch failure, we could not determine the maximum output; however, comparison with the electrically heated experiments indicates we could have gotten a little more than 30 watts from this cell. At this level the fuel pin temperature would have been about 2,000° C.

At this point, we terminated the experiment to allow disassembly and radiochemical analysis of the fuel pin. The number of fissions that occurred in the pin give an estimate for the electrical conversion efficiency of this cell of about 5%. This agrees well with similar geometries tested with bombardment heating.

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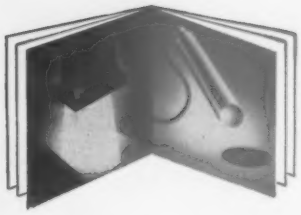

APPLIED RADIATION CASE HISTORY NO. 2

Tracer Method Examines Human Blood Circulation

Injecting tracer into a vein and sampling from an artery permits medical doctors to measure cardiac output. Studying the counting rate as a function of time often reveals abnormalities of the heart

FIRST MEMBER of this Applied Radiation Case History series was the story of suture sterilization at Ethicon (NU, March '59, p. 86). Future members will describe other successful uses of radionuclides and high-energy radiation. We hope that you will find them useful—that they will suggest extension of the methods.

BLOOD FLOW IS among the most interesting and important hydraulic systems that yield their secrets to radiotracer examination. At the Columbia-Presbyterian Center, New York City, Samuel R. Powers, Jr.,* and his associates developed a rapid radiotracer measurement of cardiac output—pumping rate of the heart (*1–3*). Resident surgeons used it routinely and studied counting-rate curves to detect such abnormalities as shunts and restrictions in the circulation.

More recently the method has seen limited use, but its inventor feels that it offers significant advantages that should be exploited. Its greatest usefulness is that it permits rapid screening of children to determine whether they are suffering from congenital heart defects. The time it saves can be spent on more careful examination of patients

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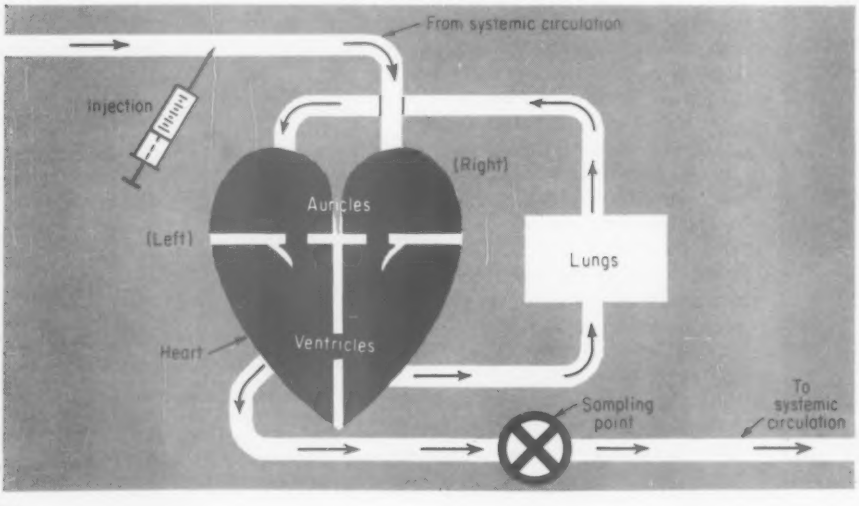
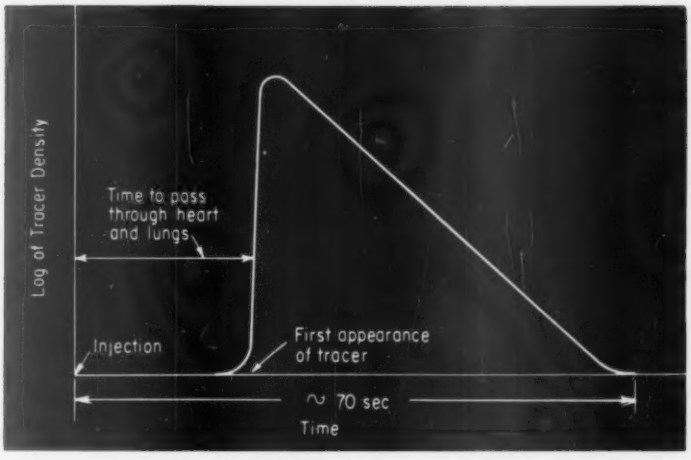
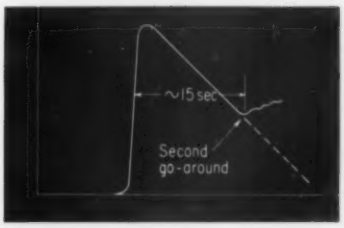
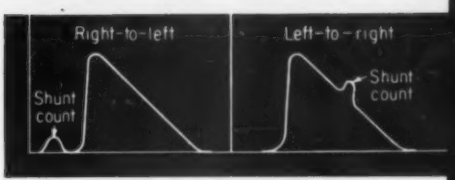


FIG. 1. BLOOD FLOW is traced by injecting radioactive material as blood enters heart. After trip through heart, lungs, and heart again, small sample is withdrawn and counted







FIGS. 2–4. IDEALIZED COUNTING CURVE rises quickly after time required for tracer to pass through heart and lungs, then decreases logarithmically with time constant characteristic of cardiac output. IN PRACTICE decrease is only until tracer reappears at sampling point after passing once through systemic circulation. HEART SHUNTS cause abnormal counting peaks before or after main peak

By R. HOBART ELLIS, Jr., Associate Editor, NUCLEONICS

who need it after preliminary check.

The method is a modification of a familiar—but cumbersome—dye-dilution method; beta-emitting $Na^{24}Cl$ is injected instead of a dye. A beta emitter enables accurate counting of localized samples. On the other hand, it requires careful counting techniques. For the tracer-dilution measurements two special sampling and counting systems have been devised. One spreads the blood sample into a thin film running under the window of a thin-window G-M tube. Another uses the weight of a slowly flowing mercury column to draw the sample from an artery through an internal, thin-walled helix in a special G-M tube.

Tracer methods are not strangers to blood-flow measurements. As described in the box on page 58, investigators have used soluble gamma emitters and external counters. Others have used Kr^{85}.

Medical Problems

A simple schematic of blood circulation through heart and lungs is shown in Fig. 1. Blood from the veins of the systemic circulation enters the heart at the right auricle, passes to the right ventricle, goes next to the lungs, and returns through left auricle and left ventricle to the arteries of the systemic body circulation.

An examining physician would like to know many things about this circulation. What is the cardiac output (pumping rate of the heart in liters per second) from each of the ventricles? How large are the chambers of the heart? Is there abnormal leakage between the two ventricles? Do abnormal restrictions in the blood vessels create abnormal pressures at different points of the system? Measurements must be made with a minimum of disturbance and without damaging the patient.

Several methods are available for measuring cardiac output; none is ideally convenient. The so-called Fick method measures oxygen concentrations in the blood entering and leaving the lungs and compares this with oxygen consumption measured with a face mask. A catheter is required in a vein and a needle in an artery. The patient must be resting.

Angiocardiography is another method. This is the introduction of an opaque substance into the blood followed by fast-sequence X-ray photographs. The method is subject to the hazard of X-ray exposure and general inconvenience.

A tracer-dilution method uses either Evans blue dye or a radionuclide and measures the dilution of the tracer as it passes through heart and lungs. Except for some inconveniences in counting, the radiotracer method is simplest of all. Its greatest usefulness is in congenital heart disease. Observation of a counting trace offers a simple, rapid method for finding abnormalities.

Dilution Method

Using either a dye or a radiotracer one can measure normal cardiac output as shown in Fig. 1. The tracer is injected into a vein (ideally the large vena cava that enters the heart) as the blood is returning from the systemic circulation. Turbulence in the heart mixes the tracer thoroughly with the blood in the heart. Samples are withdrawn

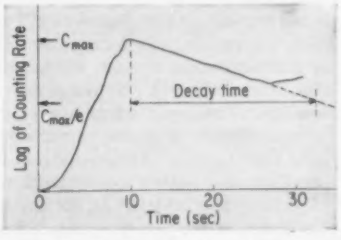


FIG. 5. EXPERIMENTAL CURVE has slow rise, well defined decrease

from a major artery through which the blood returns to the systemic circulation after its trip through the lungs.

When the tracer is a dye, samples are delivered into test tubes that are changed at half-second intervals. Centrifuging separates dyed plasma from red cells. Then spectrophotometry measures dye concentration.

Powers's radiotracer method substitutes Na^{24} for the dye, continuous sampling for the changing test tubes and beta counting for the spectrophotometry. Figure 2 shows an idealized, normal curve of counting rate as a function of time. Its size and shape can be used to determine the size of the heart and cardiac output. Abnormalities in the curve are often sensitive indicators of abnormalities in the circulation system.

Counting-rate curve. To interpret the ideal curve one assumes that the tracer reaches the heart all at once and is instantaneously mixed with the blood in the chamber that it enters. There is no increase of counting rate after injection until the tracer has had time to flow through the heart, out to the lungs, through the heart a second time and then out to the sampling point. Then the counting rate rises to a peak that depends mainly on the amount of tracer and the volume of blood in which it is mixed. From the peak the counting rate decreases along an exponential curve (a straight line on the logarithmic scale of Fig. 2). The slope of the curve indicates cardiac output; larger output corresponds to steeper slope. An integration gives the area under the curve, and this can be compared with the total amount of tracer for purposes of scaling and normalization.

In practice the exponential decrease does not return all the way to the background level. The tracer flows through the systemic circulation and comes around to the sampling point on a second trip before the descent is complete. Figure 3 is an idealized representation of the result. The counting-rate decrease continues for about 15 sec. Then it starts to rise, comparatively slowly. By this time additional mixing and disappearance of the tracer have diluted and spread the original slug of radioactivity so that the curve is badly defined. All useful information comes from extrapolating the first-time-through curve and neglecting the rest.

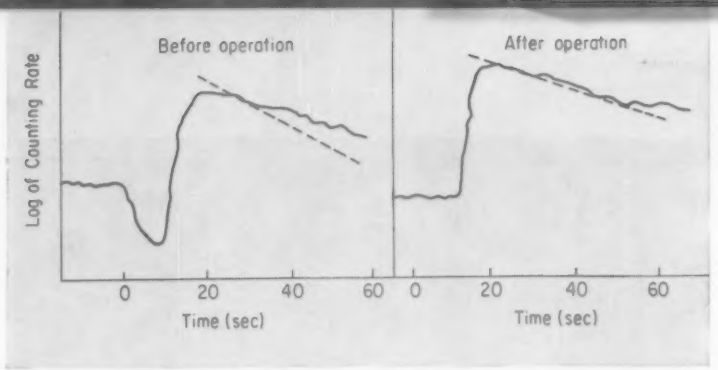


FIG. 6. CORRECTING SHUNT changes slow decline to more rapid one and removes counting peak caused by shunt. True zero is dip in left-hand curve. Counting rate at injection is caused by tracer in syringe

Abnormalities. Heart shunts and valvular stenosis are among heart abnormalities that show up on the counting-rate curve. A shunt occurs when a defect allows blood to flow through the wall that separates the two ventricles. Valvular stenosis refers to an unnatural constriction at a valve in a heart chamber. This frequently occurs in the vessel through which the blood flows out of the heart to the pulmonary circulation. The result is abnormal back pressure in the heart.

A shunt often allows blood to flow from the right ventricle to the left one, bypassing the lungs. If it functions this way, it is called a right-to-left shunt. Abnormal conditions like a valvular stenosis at the outlet to the systemic circulation may cause a reverse flow. The result is a left-to-right shunt.

Figure 4 shows idealized forms of the curves that occur as the result of shunts in the heart. In a right-to-left shunt, some of the tracer reaches the sampling point before the main counting-rate rise. The curve shows a small counting peak between the time of injection and the time required for flow through heart and lungs. In a left-to-right shunt the abnormal counting pulse occurs during the descent of counting rate as the tracer is evacuated from the heart.

More Tracer Methods for Circulation Problems

Among tracers used in other methods for studying human blood flow are I^{131}-labeled human albumin and radioactive Kr^{85}. The labeled albumin has been used recently to measure coronary flow—the flow of blood to the muscles of the heart. Kr^{85} has been used in several ways. It escapes from the circulation in the lungs; so it can be used to measure the pumping rate of the right side of the heart only (see Fig. 1).

In measuring coronary flow, 20 μc of I^{131}-labeled albumin is injected into a vein (4, 5). A G-M counter is placed over the heart and the counting rate is recorded as a function of time. Three peaks appear—one as the tracer reaches the heart, one as it goes through the lungs and returns to the heart, and one as the tracer goes into the systemic circulation. A separate count is taken over one of the carotid arteries—the two chief arteries in the neck that supply the head. This count is used to establish the time at which systemic circulation starts.

A smooth curve through the counting-rate points represents the heart flow and another, superimposed above the first, represents the coronary flow. A planimeter measure of the area of the second curve indicates the magnitude of coronary flow.

By adding Kr^{85} to the inspired air, investigators have measured blood flow to particular organs (6,7) and detected shunts in the heart (8). Recently studies have shown that Kr^{85} dissolved in Evans blue dye or saline solution and injected into the right auricle escapes almost completely from the circulating blood as the blood passes through the lungs (9). Thus one can extract samples from the pulmonary artery between heart and lungs and count it to measure cardiac output. The great advantage of the method is that it enables continuous measurements of cardiac output while the patient changes from rest to exercise and back to rest. This is difficult or impossible with other methods. For the continuous-injection experiments saline was labeled at a concentration of 3 $\mu c/cm^3$ and injected at 9.2 cm^3/min; 5-cm^3 samples were withdrawn from an artery of the arm (for corrections in calculation) and the pulmonary artery. The results compared well with those obtained by the Fick method when it was possible to use both together.

Actual Curves

Figure 5 shows an experimental curve obtained by using the tracer method in a dog. As one would expect, the rise of counting rate is gradual, rather than abrupt. The descent is a smooth, essentially straight line for ~15 sec. Thereafter a second rise occurs as the tracer reappears in its second trip through the system.

A corrected anomaly in a human patient is indicated by the two curves of Fig. 6. The pre-operation curve shows the effect of a shunt. The counting-rate decrease is ill defined and there is a small rise superimposed on the fall. The rise indicates the presence of the shunt.

After a corrective operation the counting curve is essentially normal. The clearly defined logarithmic fall measures an increased cardiac output.

Portions of these two curves that precede the main counting-rate peak are not significant. The counting rates at these times are caused by the nearness of the injection syringe to the counting apparatus.

Choice of Tracer

The ideal isotopic tracer is one with a disintegration half-life of a few days, a moderate-energy beta emission and a short biological half-life. Short half-lives and low-energy emissions make possible the use of larger concentrations for medical purposes. On the other hand a half-life shorter than a few days leads to inconvenient problems in shipping, storing and handling. Beta emission permits counting a small sample without interference from portions of the tracer in the system and near it.

Powers and his associates have used 20 μc doses of Na^{24} (1.39-Mev beta, 15.0 hr) administered with normal saline solution in the form of NaCl. It is eliminated rapidly from the systemic circulation by the kidneys and is free from any tendency to concentrate selectively as iodine does in the thyroid. Its half-life is inconveniently short. Another possible question in its use is whether it disappears from the circulation through the capillaries in the lungs. At the moment it appears that it does not.

Other blood tracers are red cells incubated in K^{42}, I^{131}-labeled albumin and Kr^{85} (see box). Incubated cells have the advantage, for some purposes, that they remain in the circulation system. But incubation is cumbersome, and K^{42} has an inconveniently short half-life—12.5 hr. Albumin labeled with I^{131} offers an 8-day half-life. Its low-energy betas require higher doses to get the same accuracy as with Na^{24}. With positron counting one might hope to use 2.6-yr Na^{22} as a blood tracer.

Instrumentation

Two special counters and a special sample-withdrawal apparatus have been used in Powers's circulation studies. The first counter spreads the emerging blood in a thin film to enable effective counting of the beta particles. It is shown in Fig. 7. Blood flows into the machined channel in the base. It spreads out in a thin film confined between the plateau in the machined channel and the 0.001-in. polystyrene plate above. Beta particles from the thin layer go through the holes in the cork gasket and brass plate to reach a thin-window G-M tube. A slight upward tilt assures filling of the chamber, and the drainage is collected in a shielded container to keep Na^{24} gamma photons from contributing to background. It might be possible to improve detection sensitivity by using anticoincidence methods of beta counting.

Output from the counting system of Fig. 7 goes to a counting-rate circuit with a 1.5-sec time constant. Counting accuracy at the peak of the curve is ~4%. The long time constant eliminates extraneous background effects, but it also eliminates some evidence of abnormal flow that might be useful information.

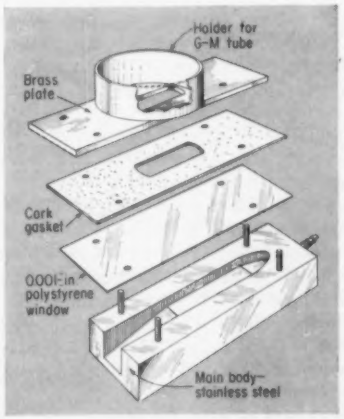


FIG. 7. SPECIAL SAMPLER spreads blood in thin film under G-M tube to permit counting Na^{24} betas

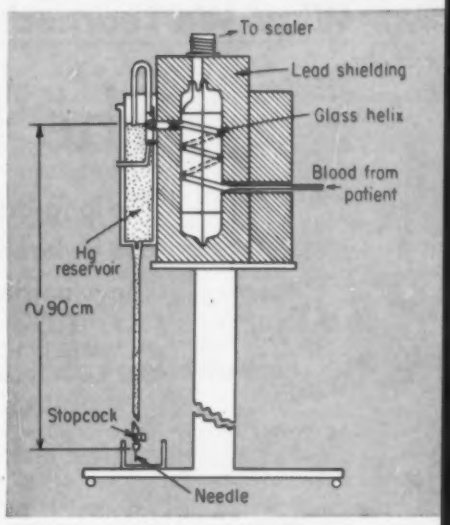


FIG. 8. ELABORATE SAMPLER uses weight of mercury column to draw blood through internal helix in special G-M tube surrounded by lead

Another sensitive detector is a special G-M tube. Nucleonic Corp. of America built it with a thin-walled glass helical tube inside the main envelope. The helix conducts the fluid to be counted. It has a length of 10 cm and a wall thickness of 3 mg/cm². Its radius is 0.1 cm.

The tube is shown in Fig. 8 with the special system used to ensure a constant, controlled rate of flow through the helix. Mercury flows from a 90-cm-high column at a rate determined by the needle at the outlet. The suction draws blood at a rate of 10 cm³ in 30 sec. This is fast enough to cause one complete change each second in the helix. The total amount of blood required for a test is 15–20 cm³. Lead shielding confines gamma radiation.

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What We Learned from

The PRDC Case

The long-drawn-out hearings established that atomic energy can be handled by traditional administrative processes. They contributed to more realistic hazard evaluation

By JAMES L. MORRISSON, *Ginsburg, Leventhal, Brown and Morrisson, Washington, D. C.*
and B. JOHN GARRICK, *Holmes and Narver, Inc., Los Angeles*

As atomic energy becomes an accepted feature of the American scene, it is natural that the atomic industry should also become subject to the normal processes of public hearing and contested litigation associated with administrative procedure in the U. S.

AEC has recently completed its first such contested hearing. Formally entitled *Matter of Power Reactor Development Company, Docket No. F-16*, it concerned the continuation of a construction permit for the Enrico Fermi fast breeder reactor at Lagoona Beach, Mich.

The hearing came as a surprise to people in and out of AEC. It required a departure from the rather informal methods of staff consideration of reactor safety problems that AEC had been using. It produced a voluminous public disclosure of the details, technical and financial, of the project. It presented the interesting spectacle of a Hans Bethe or a Harvey Brooks kept on the witness stand for days of interrogation by lawyers none of whom could pass a college freshman course in physics. It involved a very large expenditure of time, energy, and money.

There is a natural tendency among people eager to get on with the job of building reactors to wonder what all the shouting was about. Did the hearing have to happen? Did it have to take so long? What were the real issues and why did they have to be decided at this time? What good did the hearing accomplish? What lessons have been learned from it?

A possible answer to these questions is to say that—since AEC's decision, after over two years of hearing procedures, is to continue in effect the construction permit which it had originally issued without holding a hearing—the hearing was a complete waste of time. It is our view, however, that the hearing provided a useful service to the atomic energy industry, and contributed significantly to a number of constructive developments. It demonstrated that atomic energy is not a special case in our society, but is capable of being handled by the traditional legal and administrative procedures by which controversies in other fields are resolved. It allayed a threatened crisis of public confidence in AEC's regulatory procedures and requirements. It clarified the purpose and significance of the construction permit in AEC's regulatory scheme. It contributed to the development of a more realistic and integrated approach to reactor safety analysis. And it provided an impetus for strengthening and accelerating AEC's program of research and development in reactor safety.

They Were There

The authors of this article were members of the so-called "separated staff" appointed to represent AEC in the PRDC hearing. Morrisson, member of the AEC's Office of General Counsel from 1953 to 1957, was trial counsel for the AEC staff in the PRDC hearing. Garrick, a nuclear physicist, was a member of AEC's Hazards Evaluation Branch from its inception in 1955 to 1957 and provided technical guidance for the AEC staff at the PRDC hearing. This article expresses only their personal views.

1. The hearing demonstrated that reactor safety issues can be handled by traditional administrative processes

The Atomic Energy Act of 1954, following the pattern set by the Federal Communications Act for radio and television licenses, established a two-stage procedure in which the applicant must first obtain a construction permit, then an operating license. It provided for intervention in the licensing proceedings by any person whose interests might be affected, and for public hearing.

At the time this legislation was passed, few envisaged what kind of issues might arise for hearing. Thus in a sense the conduct of a contested public hearing in the PRDC case can be regarded as a kind of experiment, to determine whether the technical issues could be presented and decided in the form and manner normally used in the U. S. for contested legal and factual issues. The experiment was conducted under somewhat adverse circumstances: the case had highly political overtones, and implicit in it were questions of public vs. private power, labor vs. management, and AEC secrecy—as well as personalities.

Nevertheless, the experiment established that the technical materials of the reactor art can be handled by normal legal and administrative processes. This may seem a truism, but we think it marks an important change in attitude. Atomic energy has at times been regarded as unique and mysterious, both because of its technical novelty and

because of the secrecy with which it once was shrouded. Thus the holding of a publicly contested hearing—in which lawyers cross-examine to their heart's content into such esoteric phenomena as prompt and delayed temperature coefficients of reactivity, resonance instabilities, etc.—afforded a demonstration that nuclear physics and engineering are no different from other technical matters with which the law and the forces of public opinion have to deal. As a corollary, the authors' own experience indicates that a scientist and a lawyer can each profit by the collaboration which such a hearing imposes.

The case demonstrated also that AEC secrecy was not an impediment to the use of public hearing procedures. The union intervenors sought to make secrecy a major issue in the case by demanding access to classified documents without obtaining security clearances. But, as the hearing progressed, there was only one point (the price of plutonium) on which a need for such access was demonstrated. Once that price was declassified—as it was during (and in part as a result of) the hearing (*6*)—the secrecy issue lost any real importance. Although the unions continue to urge it, they have made no persuasive showing of prejudice from their lack of access. However, it may be too early to be sure that secrecy will not present a problem in any civilian reactor case that may arise.

Having said that the hearing process worked, one may still ask whether there is a better way to get the same results. Technical review and evaluation are normally the best way to decide on the safety of a reactor project. But in the infrequent case where there is a contest between opposing private parties, or where the judgments of the applicant and AEC differ, the hearing process affords an opportunity to challenge the technical judgment of both the applicant and AEC and thus assures the public that its interests will be protected. Moreover, the ultimate issue is not one of technical judgment but of values: how great a risk of injury to the public is "undue"? We are not aware of any alternative to the hearing process that will serve as well to assure the public that there has been adequate opportunity to challenge the technical judgments on which its safety depends, and to identify the ultimate value judgments by which any controversy must be resolved.

2. It assured public confidence in AEC's safety controls

Prior to the passage of the 1954 Act, all reactors (with one exception) were owned by the U. S.; review of their safety was treated as an internal matter, and frequently involved classified information. In handling early license applications submitted under the 1954 Act this habit of internal consideration lingered on: the license applications, including the applicant's safety analysis, were made publicly available, but not all the materials considered by AEC were made a part of a public record. And the evaluations on which AEC relied, those both of its own staff and of ACRS, were treated as internal documents and denied public disclosure.

The public impression created by the PRDC case was

How the Case Unfolded

Here is a resume of the PRDC case (1).

The proposed PRDC reactor is a heterogeneous fast breeder reactor of 100-Mw(e) rated capacity, fueled with highly enriched uranium and cooled with sodium (2). It is to be operated by a nonprofit membership corporation, Power Reactor Development Co. (PRDC), formed by 26 utility and industrial companies led by the Detroit Edison Co.

The reactor is being built at Lagoona Beach on the shores of Lake Erie. Although the site provides an exclusion radius of 2,900 ft and has a population of only 600 within 2 miles, it is located in the most densely populated part of Michigan, within 25–30 mi of the centers of Detroit and Toledo, Ohio.

PRDC's application for license was filed Jan. 6, 1956. On June 10, 1956, AEC's Advisory Committee on Reactor Safeguards (ACRS) wrote a letter to AEC's General Manager which, while adhering to ACRS's general practice of not making a recommendation for or against issuance of a construction permit, raised a number of serious questions about the project (3). Excerpts from this letter were released by Commissioner Murray June 29, 1956 (4) but the full text of the letter was not made public until AEC's order of Oct. 8, 1956 (5). On Aug. 4, 1956, AEC issued a "provisional construction permit," which failed to make any finding in the terms called for by AEC regulations (that there was "reasonable assurance" that such a reactor could be safely operated at that site) although an intent to make such a finding may be inferable from the language of the permit.

On Aug. 31, 1956, three labor unions unexpectedly filed petitions to intervene n the licensing proceeding and requested a hearing. PRDC opposed neither the intervention nor the hearing. On Oct. 8, 1956, AEC issued an order setting down for hearing the question whether the construction permit should be continued in effect. It refused, however, to suspend the permit pending the hearing. After certain preliminary motions and conferences, and a tour of Argonne National Laboratory by the hearing examiner and all counsel, the hearing began Jan. 8, 1957, and was concluded Aug. 7, 1957. During the hearing the State of Michigan was allowed to intervene. Final briefs were filed Nov. 29, 1957; oral argument was had before AEC May 29, 1958; AEC handed down its tentative decision Dec. 10, 1958; and its decision became final May 26, 1959.

The evidence received at the hearing was voluminous: 468 pages of testimony were received in narrative form; the stenographic transcript totals 3,919 pages; 83 exhibits were received in evidence. Witnesses on safety matters, in addition to PRDC's own staff, were a distinguished group: Hans Bethe, Norman Hilberry, Kenneth Davis, and six of the 13 members of ACRS.

The hearing process was unduly time-consuming and burdensome. This was the result partly of the setting of political controversy in which the case arose, and partly of the fact it was the first such hearing. Thus, because AEC had to borrow a hearing examiner from another Federal agency it did not authorize him to recommend a decision; consequently the process of decision was significantly delayed and the examiner was less willing than he otherwise might have been to exclude irrelevant or repetitive evidence. AEC now has its own examiner, and is not likely again thus to limit his power.

In addition, a major part of the testimony was addressed to financial issues. AEC's decision, by resting its conclusion of financial qualifications on reasonable probabilities including the general financial strength of the sponsors, and by rejecting a requirement to show cash on hand to meet all contingencies, should make it possible in future construction-permit cases to handle financial evidence much more briefly. Hence there is good reason to believe that any future contested hearing could be handled with greater efficiency and expedition.

that AEC had ignored and was trying to conceal an adverse recommendation of the ACRS, and had issued a permit which did not comply with its own regulations. Since AEC also occupied the dual role of promoting the PRDC project as part of its Power Demonstration Program and regulating it, it was hardly surprising that public confidence in AEC's regulatory processes was shaken.

AEC acted promptly to remedy this situation. It set the PRDC case down for hearing, despite the fact that the unions' legal right to intervene was doubtful. It rejected attempts by PRDC to limit the scope of the hearing (*7*). It issued regulations defining what it considered to be public records (*8*). It disclosed to the unions all documents submitted to it, however informally, by PRDC in connection with the consideration of its license application. And it instructed its trial staff at the hearing to act, not as advocates in support of the construction permit which AEC had issued, but as "public counsel" responsible for ensuring that all relevant facts were developed on the record (*9*)—a responsibility which that staff undertook to discharge by independent inquiry before the hearing, by extensive cross-examination of PRDC's witnesses and by calling a number of members of the ACRS as witnesses.

The hearing, once it got underway, received little press or Congressional notice. In a sense this was regrettable. The hearing developed well-thought-out statements by outstanding experts discussing the safety problems of fast reactors and the environmental problems of the proposed site, many of which could serve as models for the safety analysis of any reactor. These deserve greater distribution and attention than they have received.

But this very lack of publicity can be interpreted as a measure of the restoration of public confidence the hearing accomplished. Once it became evident that nothing was being concealed, and that the facts provided a rational basis for letting the project go ahead, there was no longer any news story in the case. Thus, no news was good news.

In 1957, during the hearing, Congress adopted legislation requiring public hearings on all test and power reactors, and publication of the ACRS report. AEC on its own initiative now makes its staff reports public. This encourages more careful preparation of both the safety report submitted by the applicant and the staff and ACRS analyses, and stimulates consistency of decision.

The process of making the entire proceeding public is not complete. ACRS meets in private, and is free to consult documents and persons who are nowhere publicly identified. But the ACRS function is conceived of as advisory only, and its advice, as well as all facts presented by the applicant or relied on by the AEC in making its decision, are now public.

One may perhaps ask why public disclosure is important. The general public cannot understand or judge the technical issues involved in a safety evaluation. And much time is spent by technically trained persons in reducing to evidentiary form conclusions that may seem obvious to them. The answer is partly one of public relations: the public—whose safety is, after all, at stake—naturally suspects judgments arrived at in private, the basis for which cannot be evaluated by persons unaffiliated with either the government or the applicant. Moreover, the basic issues in the proceeding are issues of value judgment, involving at times a balancing between progress and safety, and hence are issues which the public is able and entitled to evaluate.

3. It confirmed the validity of AEC's construction permit procedures.

The PRDC proceeding affords, we think, a convincing demonstration of the desirability of a reasonably thorough safety analysis at an early stage in the project. For the questions raised, first by the AEC staff and ACRS and then at the hearing, provided needed emphasis on safety problems and on establishment of research and development programs of sufficient scope and with sufficient funds and priorities to find timely answers to them. The requirement of a full-scale safety review for issuance of a construction permit at an early stage in the project, while it cannot provide definite assurance of the issuance of a license, serves to identify and focus attention on the potential safety problems inherent in the general reactor concept. It sets in motion necessary investigation and remedial action, and thereby provides both the public and the licensee with considerable assurance that, when the reactor is ready to be operated, all important safety problems will have been identified and solved.

On the other hand, AEC's procedure has avoided hampering the developing reactor industry with unduly restrictive requirements. In FCC practice, as in many other fields, a permit to start building is issued only on the basis of completed plans and definitive evaluation. The unions appear to have contended in the PRDC case for a like procedure. Such a requirement would have seriously delayed the development of reactors, in which development, design and construction often overlap in time. AEC's final decision in the PRDC proceeding states explicitly that it is not necessary, in order to get a construction permit, to make the same detailed showing of assurance of public safety that will be required for an operating license. It is enough to show that the applicant will probably be able to make such a showing by the time permission to operate is requested. This does not mean that safety should not be reviewed at the construction permit stage; it means only that the standards of review for a construction permit and for operating permission differ according to the practical necessities of the two situations.

AEC's Opinion and Final Decision of May 26, 1959, is a persuasive statement of these considerations which makes a major contribution to clarification and public understanding of AEC's construction permit procedure.

4. It contributed to reactor hazards evaluation.

During the period covered by the hearing, a significant change of emphasis occurred in the field of hazard analysis. Reactor hazards analysis had its birth in the days of large exclusion radii, low fission-product inventories and government-owned facilities; accidents were assumed involving failure of all protection systems, meltdowns, fuel vaporization, and large releases of fission products. This type of analysis (taking conditions to the limit) is the easiest to make and was justified at that time since public safety was not then in jeopardy. Today, however, it is no longer possible to talk of complete releases when fission product

inventories are large, reactors are privately owned, and often cannot be isolated. Such releases might have been tolerated at Idaho Falls; they are clearly intolerable at Lagoona Beach. Hence a change of emphasis has occurred, away from theory and toward practical engineering. This trend was hastened by the PRDC proceeding.

One example concerns site location and environmental data. In a sense the crucial issue on any application for construction permit is the suitability of the site, for while core design and even containment can be modified as construction proceeds, the site, once selected, is fixed. Nevertheless the original PRDC license application—like some others—was almost wholly lacking in environmental information. When supplemental information was filed it tended to consist of raw data, unrelated and undigested. Not until the hearing was well along did one begin to see environmental data integrated with the possible occurrences in the reactor, to show the relation of environmental conditions to public safety. In our judgment this aspect of the hearing alone greatly contributed not only to an increased emphasis on environmental data in hazards evaluation generally, but also to an integrated and meaningful approach to such data.

5. It contributed to technical information concerning fast reactor safety.

To many observers it often seemed during the course of the hearing that the evidence was simply a repetition of facts already known, and that the hearing process merely impeded communication between scientists by interposing the highly-imperfect transmission medium of lawyers lacking technical training. In part this is the nature of a hearing; its primary purpose is not to develop new facts but to place the existing facts in a public record and subject them to searching examination.

But the hearing did disclose important new information. Probably the most significant such information was an able paper by Hans Bethe, which developed in detail the theory of using oscillatory power experiments as a means of exploring the dynamic behavior of a reactor under abnormal conditions (*10*). In addition, the hearing stimulated research and development by both AEC and PRDC into fast reactor safety problems.

A proposal to locate a power reactor—especially one that, like the Fermi reactor, will contain some 3-billion curies after extended operation (*11*)—in a heavily-populated area, near two large cities, obviously requires thorough examination to guard against accidental release of radiation. Each of the four large power reactor projects for which licenses were sought in 1955 and 1956 presented this problem in greater or less degree. The PRDC project was the only one in which issuance of a construction permit was contested. It presented three unique safety issues:

1. The reactor type was the most advanced and least understood of the large power reactors proposed to that time. AEC had operated one fast-breeder reactor experiment, EBR-1, from 1951 to 1955. While in general its operation was successful, it disclosed certain instabilities under unusual operating conditions. During somewhat hazardous experiments to ascertain their cause the reactor, on Nov. 29, 1955, overheated and experienced gross melting (*12*). Analysis of the melted core to determine its behavior during melting was still incomplete at the time the original PRDC construction permit was issued.

It was this relative lack of experience and the not-wholly-reassuring nature of the available experience that gave rise to doubts in many minds whether the safety problems of the proposed reactor type had yet been fully identified, and to suggestions that a prototype should be built and operated at a remote location prior to allowing the PRDC project to be operated.

2. The foregoing experience indicated two major areas of uncertainty concerning the safety of heterogeneous fast breeder reactors: their nuclear stability and the possibility of a meltdown of the core (NU, Feb. '57, p. R1).

3. The importance of these uncertainties was accentuated by the site selected, which is prone to temperature inversions that would prevent dissipation of a fission-product cloud, should one be released. The only analysis of on-site meteorological data submitted by PRDC showed a 2½-day inversion during the 20-day period analyzed.

When AEC issued its original construction permit it could be said that neither the stability nor the melt-down problem appeared inherently impossible of solution, and that there were affirmative indications that favorable solutions would be found by substantial theoretical and experimental effort and by design features whose nature could not yet be identified. It was not clear that an adequate theoretical and experimental program had been provided for, either by AEC or PRDC, or that the results of that program would be available in time to meet PRDC's then proposed date of completion of construction of Dec. 1, 1959.

By the time AEC handed down its tentative decision of Dec. 10, 1958, substantially more evidence was available, and the scope and time schedule of further investigation had been increased and accelerated. The EBR-1 experiments had given strong confirmation to the view that any instabilities could be eliminated by proper core design (*13*). A very extensive program of experimental investigation of meltdown phenomena was underway. Time schedules on the British and U. S. fast-reactor programs had been firmed up and the PRDC schedule put back so that, barring upsets, there would be available, prior to start of PRDC's test operations, almost two years of experimental operations on EBR-1 with its new core, 1½ years' testing and operation of Britain's Dounreay reactor, and perhaps several months of test operations of AEC's EBR-2.

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1. This section is based on the documents and testimony in the public record, AEC Docket No. F-16
2. A detailed description of the reactor is contained in APDA-115, filed as an exhibit to PRDC's license application. See also NUCLEONICS, **15**, No. 4, 68 (1957)
3. Joint Committee Print, A Study of AEC Procedures and Organization in the Licensing of Reactor Facilities, April 1957, p. 132
4. Hearings Before the Subcommittee of the House Committee on Appropriations, 84th Cong, 2d Sess., on Investigation of Atomic Electric Power, p. 226
5. Joint Committee Print (ref. 3), p. 117
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7. AEC Order, Dec. 21, 1956
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12. NUCLEONICS **14**, No. 6, 35 (1956)
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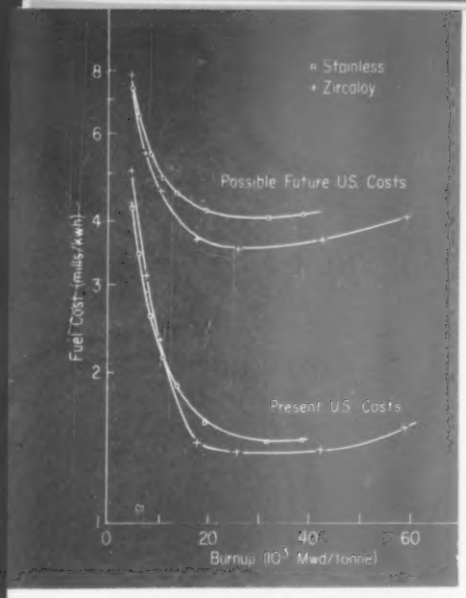

COMPARATIVE FUEL COSTS with stainless steel and Zircaloy cladding for equivalent burnup. Basis for calculation: Future costs—Pu at \$12/gm, U inventory at 12%, fabrication cost interest at 12%. Present costs—Pu at \$30/gm, U inventory at 4%, fabrication cost interest at 12%

Fuel costs have been compared, based on recent AEC prices, for Zircaloy-2 and stainless cladding in a pressurized-water reactor. Zircaloy-2 offers a lower fuel cost for burnups >12,000 Mwd/tonne

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Which for Minimum Fuel Cost —Zircaloy or Stainless Clad?

GUARANTEED PRICES recently announced by AEC for Zircaloy- and stainless-steel-clad fuel (*1*) permit a more precise comparison of the costs of cladding fuel with these two materials than was previously possible (*2, 3*).

According to the new comparison, in a Yankee-type reactor and at the current AEC plutonium price and inventory charge, Zircaloy-2 cladding would give a lower total fuel cost for all burnups >12,000 Mwd/tonne (metric ton). After 1962, when the Pu price will probably be lower and AEC may not subsidize uranium inventory, Zircaloy should be more economical at all burnups >4,500 Mwd/tonne.

In a previous economic comparison of Zircaloy and stainless in nuclear power reactors (*2, 3*), it was assumed that the only difference in fabrication costs for fuel elements would be the higher material cost of Zircaloy. However, for reactors built under the U. S.-Euratom agreement, the AEC has guaranteed prices of \$100/kg of contained U for fuel elements clad with stainless steel and \$140/kg for elements clad with Zircaloy (*1*). On the basis of these prices, we shall compare the costs of stainless-steel and Zircaloy cladding in a pressurized-water reactor, similar to the one being developed by Westinghouse for the Yankee Atomic Electric Co. (*4*).

Reactor Design

The reactor is a pressurized light-water-moderated and -cooled reactor fueled with uranium oxide (UO_2) in the form of sintered pellets (*4*). The thermal power level is 480 Mw(th); the plant will generate 134 Mw(e).

In the present design, stainless-steel cladding is used for the fuel—~60,700 lb of UO_2 enriched to 2.6 at% U^{235}. Because of the lower neutron-absorption cross section of Zircaloy-2, as compared with stainless steel, the initial enrichment of U fuel for the reactor can be lower for the same burnup with Zircaloy than with stainless steel.

One design proposed for this reactor includes 10,400 lb of stainless steel in the form of fuel cladding, 0.335-in. o.d. by 15 mil thick, with stainless-steel spacers. This design also contains 2,590 lb of Zircaloy as control-rod followers. For our modified design, it is assumed that the stainless steel would be replaced by an equal volume of Zircaloy, leading to an inventory of 8,410 lb of Zircaloy in fuel cladding and spacers and a total Zircaloy inventory of 11,000 lb.

The more pertinent performance and design data for these two reactors are given in a box on p. 65.

Nuclear Calculations

The method used to calculate reactivity, fuel isotopic composition and other reactor properties is basically that described by Pigford et al. (*5*). (See box, page 65.) One-group diffusion

Reactor Performance and Design Data

Reactor Type and Materials

Reactor type	Thermal, heterogeneous
Fuel	Slightly enriched UO_2
Moderator, reflector, coolant	H_2O
Vessel design	Pressure shell
Cladding and structural material	Zircaloy-2 or stainless steel

Operating Data

Reactor power (thermal)	480 Mw
Net electric power	134 Mw
Over-all plant efficiency	27.9%

Core Data

Lattice type	Rods on square lattice
Fuel-rod cladding o.d.	0.335 in.
Fuel-cladding thickness	0.015 in.
Fuel o.d.	0.030 in.
Lattice spacing	0.420 in.
Total number of fuel rods	23,218
Number of rods per fuel assembly	305 and 306
Number of fuel assemblies	76
Loaded core radius	74 in.
Loaded core length	102 in.
Radial reflector thickness	7.5 in.

Coolant System

Coolant flow	37.0×10^6 lb/hr
Coolant temperatures in core	
Inlet	487° F
Outlet	525° F
Average	508° F
Coolant flow area	14.9 ft²
Coolant pressure	2,000 psi
Coolant pressure drop across core	9.5 psi

Material Inventories in Core

UO_2	60,700 lb	
H_2O (at 508° F)	6,320 lb	
Cladding Material:	*S.S.*	*Zr*
Zircaloy inventory in reactor	2,590 lb	11,000 lb
Stainless inventory in reactor	10,400 lb	0 lb

Material Densities at Operating Temperature

UO_2	9.971 gm/cm³
Zr	6.50 gm/cm³
S.S.	7.93 gm/cm³
H_2O	0.786 gm/cm³

Nomenclature, Basic Prices, Other Data

F_n = inventory interest rate on U
F_{fab} = interest rate on money tied up in fabrication costs
G = grams of fuel fed to reactor per kwh(e)
L = load factor (0.8 used throughout)
W_j = weight ratio of material j to weight of fuel fed to the reactor, where j takes the designations: F = fuel, U = uranium, UN = nonrecycled U, Pu = plutonium
Superscripts: o = initial value at time of reactor startup, γ = final value at end of irradiation

Unit costs

C_i = unit price for process i (\$/kg); $\bar{C}_i$ = partial fuel cost due to ith process (mills/kwh); C_1 = purchased U price, see ref. *1*; C_2 = fabrication cost = \$100 for stainless cladding and \$140 for Zircaloy cladding per kg contained U; C_7 = shipping cost, \$8.80/kg U (principally due to cost of shipping "hot" fuel for reprocessing); C_8 = reprocessing fuel = \$20.30/kg U; C_9 = conversion of $UO_2(NO_3)_2$ to UF_6 = \$5.60/kg of uranium; C_{10} = value of UF_6 sold to AEC = same cost table used as for C_1, see ref. *1*; C_{11} = conversion of $Pu(NO_3)_4$ to Pu = \$1,500/kg Pu; C_{12} = value of Pu sold to AEC = \$12,000 or \$30,000/kg Pu (see discussion)

Recovery factors

f_i = recovery factor for process i; f_8 = U reprocessing = 0.99; f_9 = $UO_2(NO_3)_2 \rightarrow UF_6$ = 1.0; f_{11} = $Pu(NO_3)_4 \rightarrow$ Pu = 1.0

Holdup times

T_i = holdup time for ith process (days), T_4 = spare fuel inventory = 30 days; T_5 = reactor operating time, obtained from results of nuclear calculations (see Tables 1 and 3); T_6 = cooling = 120 days; T_7 = shipping = 61 days; T_8 = reprocessing = 32 days; T_9 = conversion of $UO_2(NO_3)_2$ to UF_6 = 61 days

Method of Calculation

Net fuel cost = $\bar{C}_1 + \bar{C}_3 + \bar{C}_7 + \bar{C}_8 + \bar{C}_9 + \bar{C}_{10} + \bar{C}_{11} + \bar{C}_{12}^{\gamma} + \bar{C}_{UN} + \bar{C}_{fab}$

Purchased uranium	$\bar{C}_1 = W_{UN}{}^{\gamma} G C_1$
Fabrication	$\bar{C}_3 = G C_3$
Shipping	$\bar{C}_7 = W_F{}^{\gamma} G C_7$
Reprocessing	$\bar{C}_8 = f_8 W_U{}^{\gamma} G C_8$
$UO_2(NO_3)_2 \rightarrow UF_6$	$\bar{C}_9 = f_8 f_9 W_U{}^{\gamma} G C_9$
UF_6 to A.E.C.	$\bar{C}_{10} = -f_8 f_9 W_U{}^{\gamma} G C_{10}$
$Pu(NO_3)_4 \rightarrow$ Pu	$\bar{C}_{11} = f_8 f_{11} W_{Pu}{}^{\gamma} G C_{11}$
Pu to A.E.C.	$\bar{C}_{12}^{\gamma} = -f_8 f_{11} W_{Pu}{}^{\gamma} G C_{12}$
U inventory charge	$\bar{C}_{UN} = \bar{C}_1 \frac{F_n}{365}\left[\Sigma_i T_i + \frac{T_5}{L}\right]$

where $\Sigma_i T_i$ = holdup time excluding days in reactor, $\frac{T_5}{L}$ = days of reactor time, i refers to steps 4, 6, 7, 8, 9

Fabrication inventory charge $\bar{C}_{fab} = \bar{C}_3 \frac{F_{fab}}{365}\left[T_4 + \frac{T_5}{2L}\right]$

Nomenclature for Tables 1–4

N_{25} = atoms of U^{235}, N_{28} = atoms of U^{238}, W_{25} = weight ratio of U^{235} to fuel fed, N_{25}/N_U = atom ratio of U^{235} to total U, E = burnup (Mwd/tonne), N_{26} = atoms of U^{236}, N_{49} = atoms of Pu^{239}, N_{40} = atoms of Pu^{240}, N_{41} = atoms of Pu^{241}, N_{42} = atoms of Pu^{242}

Cost Calculations for Stainless Clad

TABLE 1—Stainless Cost Data (Ref. *6*)

Run No. →	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Initial values									
$N_{25}°$	0.02309	0.02564	0.02669	0.02881	0.03093	0.03306	0.03738	0.04610	0.05040
$N_{28}°$	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
$W_{25}°$	0.022291	0.024692	0.025677	0.027660	0.029635	0.031611	0.035595	0.043537	0.047406
$N_{25}°/N_{U}°$	0.0226	0.0250	0.0260	0.0280	0.0300	0.0320	0.0360	0.0440	0.0480
Final values									
E(Mwd/tonne)	1,616	5,083	6,260	8,647	11,111	13,689	19,262	31,668	38,130
Correction (%)*	−3.1	−2.8	−2.5	−2.2	−1.8	−1.5	−0.8	+0.5	+1.1
E, corrected	1,566	4,941	6,104	8,457	10,911	13,483	19,108	31,826	38,549
N_{25}	0.02117	0.02020	0.02016	0.02017	0.02020	0.02024	0.02027	0.02015	0.02010
N_{26}	0.00036	0.00101	0.001212	0.001602	0.00198	0.00237	0.00475	0.00475	0.00552
N_{28}	0.99860	0.99547	0.99439	0.99232	0.99022	0.98804	0.98334	0.97293	0.96750
N_{49}	0.001297	0.003248	0.003763	0.004670	0.005479	0.006212	0.007564	0.009877	0.010864
N_{40}	0.000058	0.000319	0.000412	0.000592	0.000764	0.000928	0.001240	0.001784	0.002015
N_{41}	0.000010	0.000143	0.000216	0.000390	0.000591	0.000815	0.001313	0.002388	0.002904
N_{42}	2×10^{-8}	0.000007	0.000013	0.000031	0.000059	0.000096	0.0002054	0.000557	0.000784

* This correction made as suggested by Cunningham; see p. 28 of Ref. *6*.

TABLE 2—Stainless Cost Summary (mills/kwh)

Run No. →	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
$\bar{C}_1$	24.344	8.833	7.525	5.977	5.055	4.443	3.631	2.781	2.541
$\bar{C}_2$	9.537	3.023	2.447	1.766	1.369	1.108	0.782	0.469	0.387
$\bar{C}_7$	0.838	0.265	0.214	0.154	0.119	0.096	0.068	0.040	0.033
$\bar{C}_8$	1.911	0.602	0.486	0.350	0.270	0.218	0.153	0.090	0.074
$\bar{C}_9$	0.527	0.166	0.134	0.097	0.075	0.060	0.042	0.025	0.020
$\bar{C}_{10}$	−21.421	−6.358	−5.129	−3.699	−2.868	−2.324	−1.638	−0.971	−0.797
$\bar{C}_{11}$	0.190	0.163	0.157	0.146	0.137	0.129	0.116	0.098	0.091
$\bar{C}_{12}$ @ \$30/gm	−3.795	−3.270	−3.134	−2.913	−2.734	−2.579	−2.325	−1.960	−1.828
@ \$12/gm	−1.518	−1.308	−1.254	−1.165	−1.093	−1.032	−0.930	−0.784	−0.731
$\bar{C}_{UN}$ @ 4%	1.075	0.597	0.570	0.551	0.553	0.566	0.608	0.719	0.781
@ 12%	3.225	1.791	1.710	1.653	1.659	1.698	1.824	2.157	2.343
$\bar{C}_{fab}$ @ 4%	0.083	0.062	0.060	0.058	0.057	0.056	0.055	0.054	0.054
@ 12%	0.249	0.185	0.180	0.173	0.170	0.168	0.165	0.164	0.163
Pu @ \$30/gm, $\bar{C}_{UN}$ @ 4%, $\bar{C}_{fab}$ @ 12%	13.455	4.206	3.450	2.602	2.146	1.886	1.602	1.455	1.465
Pu @ \$12/gm, $\bar{C}_{UN}$ @ 12%, $\bar{C}_{fab}$ @ 12%	17.882	7.362	6.470	5.452	4.893	4.567	4.213	4.069	4.124

theory, modified by using effective cross sections to allow for epithermal absorptions, is used to determine criticality for the uniform-flux reactor model.

Neutron balances were calculated as a function of time in terms of excess reactivity in the reactor. Compositions and excess reactivity were calculated at a series of time increments until the excess reactivity was found to be zero. Initial enrichment was varied from "just critical" to about 5 at% in the case both of stainless steel and of Zircaloy. With Zircaloy cladding, 1.44% enrichment is "just critical," while with stainless steel 2.26% is required.

Probably the most significant error introduced into the calculation is the result of the assumption of uniform flux over the reactor volume. Cunningham (*6*) found that a more realistic flux distribution would reduce the energy production for once-through batch operation to about 55% of that calculated for the uniform-flux model. The burnup limitations due to nonuniform flux distribution might be improved by a programmed rearrangement of fuel elements or other continuous fuel-irradiation schemes. Reduced energy production would have the effect of increasing unit fuel costs. However, since this error affects both calculations in the same way, the economic advantage of Zircaloy over stainless-steel cladding is not affected by it.

Nuclear calculations performed by

Cost Calculations for Zircaloy Clad

TABLE 3—Zircaloy Cost Data*

Run No. →	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Initial values								
N_{25°	0.014610	0.016260	0.018370	0.020408	0.025640	0.030928	0.041670	0.052630
N_{28°	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
W_{25°	0.0142206	0.0158013	0.0178152	0.0197527	0.0246916	0.0296332	0.0395187	0.049399
N_{25°/N_{U°	0.0144	0.0160	0.0180	0.0200	0.0250	0.0300	0.0400	0.0500
Final values								
Time (sec)	0.91004×10^7	2.0611×10^7	3.3341×10^7	4.5829×10^7	7.9933×10^7	11.662×10^7	19.366×10^7	27.262×10^7
E(Mwd/tonne)	2,044.8	4,623.8	7,464.0	10,239	17,768	25,791	42,384	59,045
N_{25}	0.012383	0.011738	0.011587	0.011559	0.011582	0.011659	0.012017	0.012619
N_{26}	0.0003982	0.0008053	0.0012036	0.0015657	0.0024713	0.0033692	0.0051413	0.0068951
N_{28}	0.99788	0.99536	0.99273	0.99024	0.98367	0.97682	0.96285	0.94889
N_{49}	0.0016836	0.0030294	0.0040774	0.0048851	0.006544	0.0078938	0.010122	0.012048
N_{40}	0.00012417	0.00037723	0.00063797	0.00086211	0.0013548	0.0017639	0.0024291	0.0029883
N_{41}	0.00002816	0.0001619	0.00037679	0.00061347	0.0012755	0.0019407	0.0031481	0.0042061
N_{42}	0.00000084	0.00000974	0.000033288	0.000068867	0.00021298	0.00041684	0.00091851	0.0014683

* Unpublished calculations made by Goller for his thesis (*7*).

TABLE 4—Zircaloy Cost Summary (mills/kwh)

Run No. →	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
$\bar{C}_1$	9.815	5.085	3.750	3.155	2.456	2.141	1.860	1.741
$\bar{C}_2$	10.225	4.522	2.801	2.042	1.177	0.811	0.493	0.354
$\bar{C}_7$	0.641	0.283	0.175	0.127	0.073	0.050	0.030	0.021
$\bar{C}_8$	1.462	0.644	0.397	0.288	0.164	0.112	0.067	0.047
$\bar{C}_9$	0.403	0.177	0.109	0.079	0.045	0.031	0.018	0.013
$\bar{C}_{10}$	−7.518	−3.045	−1.845	−1.338	−0.773	−0.538	−0.343	−0.265
$\bar{C}_{11}$	0.197	0.170	0.150	0.137	0.122	0.101	0.084	0.074
$\bar{C}_{12}$ @ \$30/gm	−3.946	−3.395	−3.007	−2.745	−2.438	−2.018	−1.682	−0.489
@ \$12/gm	−1.578	−1.358	−1.203	−1.098	−0.975	−0.807	−0.673	−0.596
$\bar{C}_{UN}$ @ 4%	0.469	0.336	0.323	0.334	0.393	0.467	0.633	0.811
@ 12%	1.406	1.007	0.969	1.003	1.179	1.402	1.900	2.432
$\bar{C}_{fab}$ @ 4%	0.107	0.089	0.083	0.081	0.078	0.078	0.077	0.078
@ 12%	0.322	0.266	0.249	0.243	0.235	0.233	0.232	0.233
Pu @ \$30/gm, $\bar{C}_{UN}$ @ 4%, $\bar{C}_{fab}$ @ 12%	12.070	5.043	3.102	2.322	1.454	1.390	1.392	1.540
Pu @ \$12/gm, $\bar{C}_{UN}$ @ 12%, $\bar{C}_{fab}$ @ 12%	15.375	7.751	5.552	4.638	3.703	3.536	3.668	4.054

Goller (*7*) and Cunningham (*6*) led to tables of compositions and burnup as shown in Table 1 for stainless steel and Table 3 for Zircaloy-2 cladding.

Cost Calculations

The present study revised previous cost calculations (*5–8*) in the light of the most recent guaranteed fuel prices published by the AEC (*1, 9*). The calculation method and the basic price data, holdup times and recovery factors are shown on p. 65. The nomenclature is that of Pigford et al. (*5*).

These same costs were used for all steps in the process except fabrication, whether stainless or Zircaloy was used. The differing costs for stainless steel or Zircaloy fabrication have now been fixed and published by the AEC (*1*). These costs include the charges for conversion of the hexafluoride to the dioxide, the cost of the zirconium or stainless-steel tubes and the cost of fabrication (*10*). The cost calculations, using the nuclear calculational data as a basis, led to tables of partial and total costs as shown in Table 2 for stainless-steel cladding and Table 4 for Zircaloy-2 cladding.

There is some question as to the price that should be used in the case of three of the partial costs. The AEC at present allows \$30/gm for Pu of the quality derived from this reactor. However, this price is fixed only until 1962, and it is expected that thereafter the price of \$12/gm may apply in the

(*Continued on page 100*)

Relating Basic Core Parameters

By R. C. WALKER
Hanford Atomic Products Operation, General Electric Co., Richland, Washington

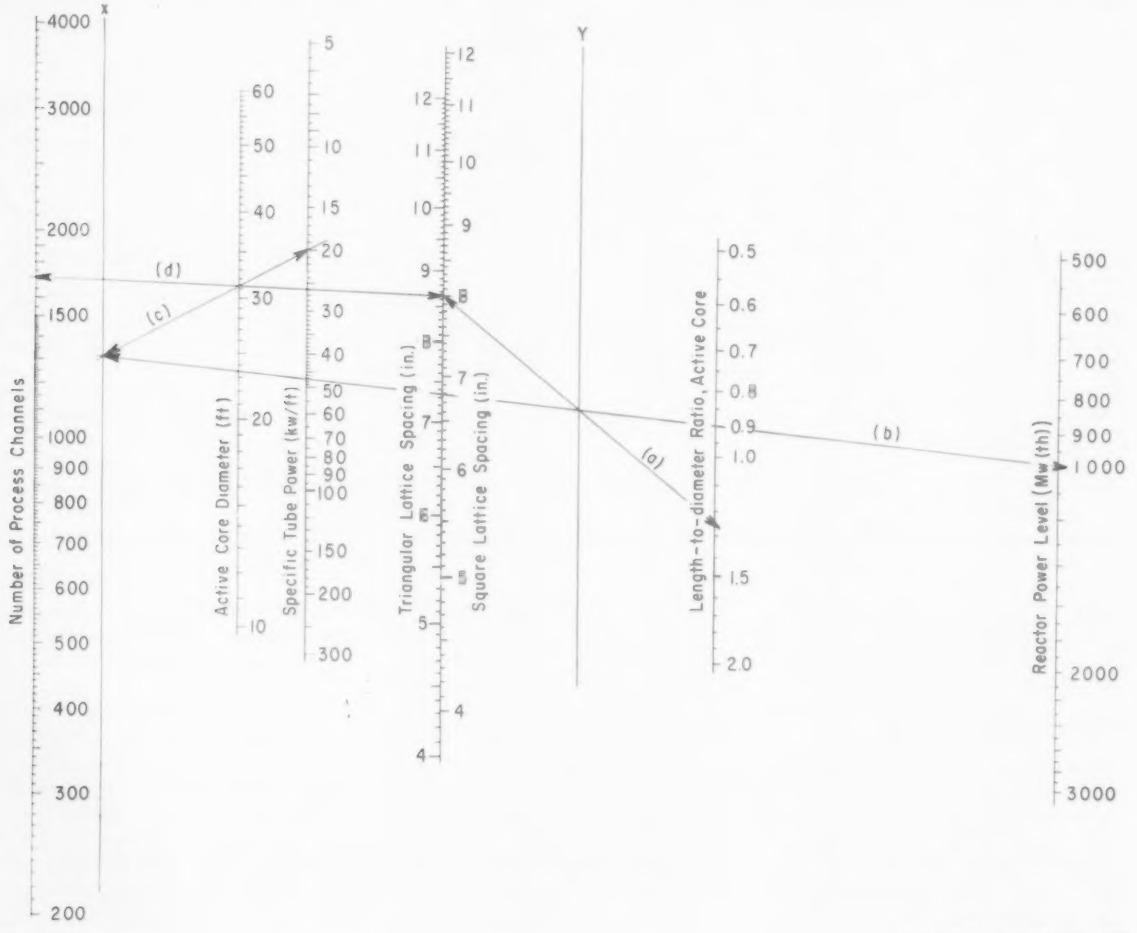
THIS NOMOGRAM is for establishment of related values of basic core parameters before detailed reactor-design computations. After such computations are completed, it can be used to estimate the effect on all other parameters of varying one of them slightly.

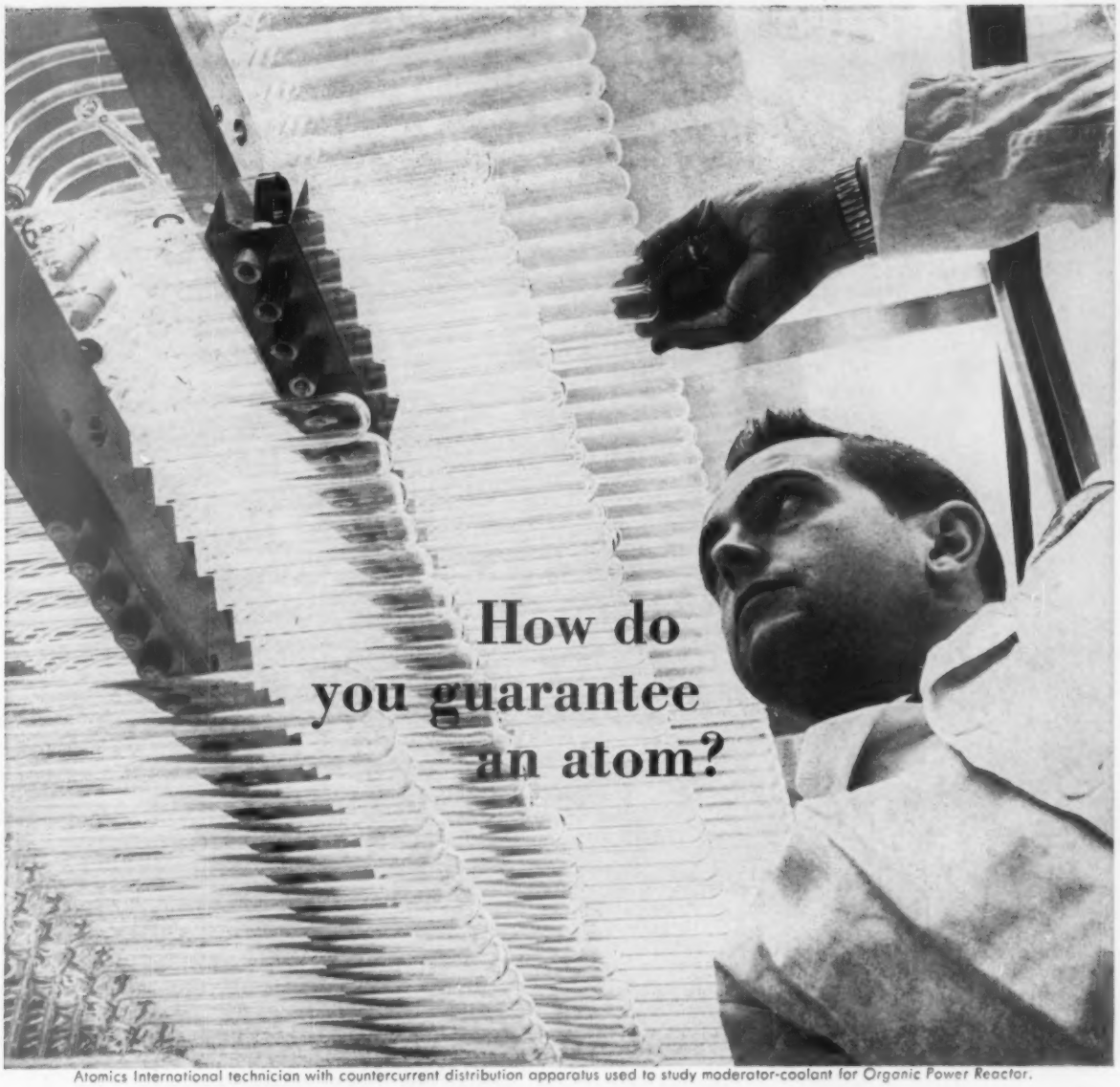
The parameters of the figure are common to all reactors in which parallel process channels are arranged in a symmetrical lattice in a cylindrical core. For lattice cells that are not squares or equilateral triangles, the designer can compute the equivalent square lattice area and then use the chart directly.

Basic equations that are solved are $N = (P/fLq) \times 10^5$; $N = 0.7854D^2/A$; $L = KD$. Here N = number of process channels; P = reactor power [Mw(th)]; f = flattening efficiency; that is, ratio of actual reactor power to power if all tubes are maximum-performance tubes; L = length of active zone; q = average specific power in maximum-performance channel (kw/ft); D = active-core diameter (ft); A = area of one lattice unit (ft²); K = length-to-diameter ratio of the active reactor core.

The chart assumes a constant 75% flattening efficiency f. With care the over-all error in using the chart should be <1%.

Example. *Given:* length-to-diameter ratio, 1.25; lattice, 8 × 8 in., square; power level, 1,000 Mw; specific tube power, 20 kw/ft. *Required:* active core diameter and number of process channels. *Solution:* Construct lines *a*, *b*, *c*, *d* in that order to find core diameter, 31.1 ft; number of process channels, 1,710.





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Determining Cladding Thickness of Fuel Elements by X-Rays

By BEVERLEY JAMES LOWE,* PAYSON D. SIERER, Jr.† and ROBERT B. OGILVIE
Massachusetts Institute of Technology, Cambridge, Mass.

Several methods of determining the variations in cladding thickness by nondestructive techniques either have been proposed or are in actual use (*1*). These methods, however, are either too slow or are not applicable for all cladding materials because of wide variations in density and atomic number.

In the hope of developing accurate and fast quality-control methods, we studied the use of fluorescent X-ray and Compton-scattering techniques. We conclude that these techniques are feasible for continuous quality control, but that equipment must be designed for such processes. This new equipment must be of sufficient energy (at least 150 kev) and intensity, it must be adequately stabilized and it must be capable of adjustment for various geometries.

X-Ray Fluorescent Techniques

X-ray fluorescence has been used to gage the thickness of very thin plating (*2*), but fuel-element cladding presents increased difficulties because it is considerably thicker. The characteristic *L* series of uranium has unacceptably high attenuation coefficients in certain cladding materials (e.g., niobium and zirconium), but reasonable attenuation coefficients for cladding materials of high atomic number can be expected with the higher-energy uranium *K* series.

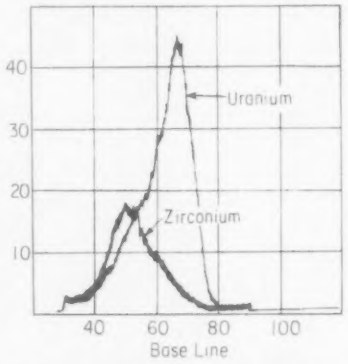


FIG. 2. PULSE-HEIGHT distribution of energy spectrum from uranium and zirconium

Uranium *L*-series technique. Initially, we tried using the *L* series of uranium fluorescence. The specimen was a flat disc (1 in. dia × ¼ in.) of natural uranium. Cladding was simulated by overlaying foils of known thickness of the desired cladding material. The cladding materials studied were aluminum, type 304 stainless steel and zirconium. These materials represent a wide variation in atomic number and density.

A standard Norelco fluorescent-analysis unit was used to excite and analyze the fluorescent radiation. Current and voltage input to the X-ray tube was stabilized to 0.1%. The uranium $L_{\alpha 1}$ spectral line was used in the analysis because it is the most intense.

As expected, only the aluminum could be measured, *L*-series radiation is too readily absorbed in stainless steel and zirconium. Figure 1 shows a curve of data normalized to the intensity recorded for twenty mils of aluminum cladding. Analysis of the data indicates that an error of 3% (<1 mil) can be expected. In measurements on actual fuel elements, however, the results were reproducible to within 0.1 mils. This indicates that the method of assembling the specimens from laminated foils is the major source of error. We concluded that, with a carefully machined series of calibration specimens, aluminum-cladding thickness can be measured to accuracies of <1%.

Uranium *K*-series technique. The attenuation coefficients of stainless steel and zirconium are considerably lower for radiation corresponding to the uranium *K* series. Available fluorescent-analysis units, however, are not designed to produce X-rays of sufficient energy to excite the *K* series of uranium. It was necessary, therefore, to adapt a 150-kev industrial X-ray unit for this phase of the investigation. A single-channel pulse-height analyzer was used for spectrum analysis. The specimen's face plane was oriented at 45 deg to the incident and take-off beams.

Typical pulse-height distributions from pure uranium and pure zirconium are shown superimposed in Fig. 2. The peak at 67 v represents the uranium *K* fluorescent series, but the peak occurring at 50 v represents the scattered spectrum rather than zirconium fluorescence.

A series of measurements were made with varying thicknesses of zirconium or uranium. From these measurements a curve of intensity vs cladding thickness was developed (Fig. 3). From an analysis of the data, we concluded that an accuracy of 3% with 30 mils of zirconium cladding could be obtained.

An analysis of aluminum was not

* PRESENT ADDRESS: Mare Island Naval Shipyard, Vallejo, Calif.

† PRESENT ADDRESS: U.S.S. duPont, DD-941, FPO New York, N. Y.

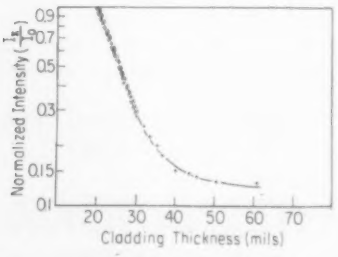


FIG. 1. INTENSITY of uranium *L*-series fluorescence radiation vs thickness of aluminum cladding (background included)

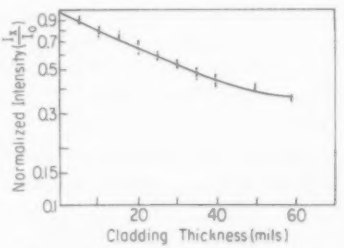
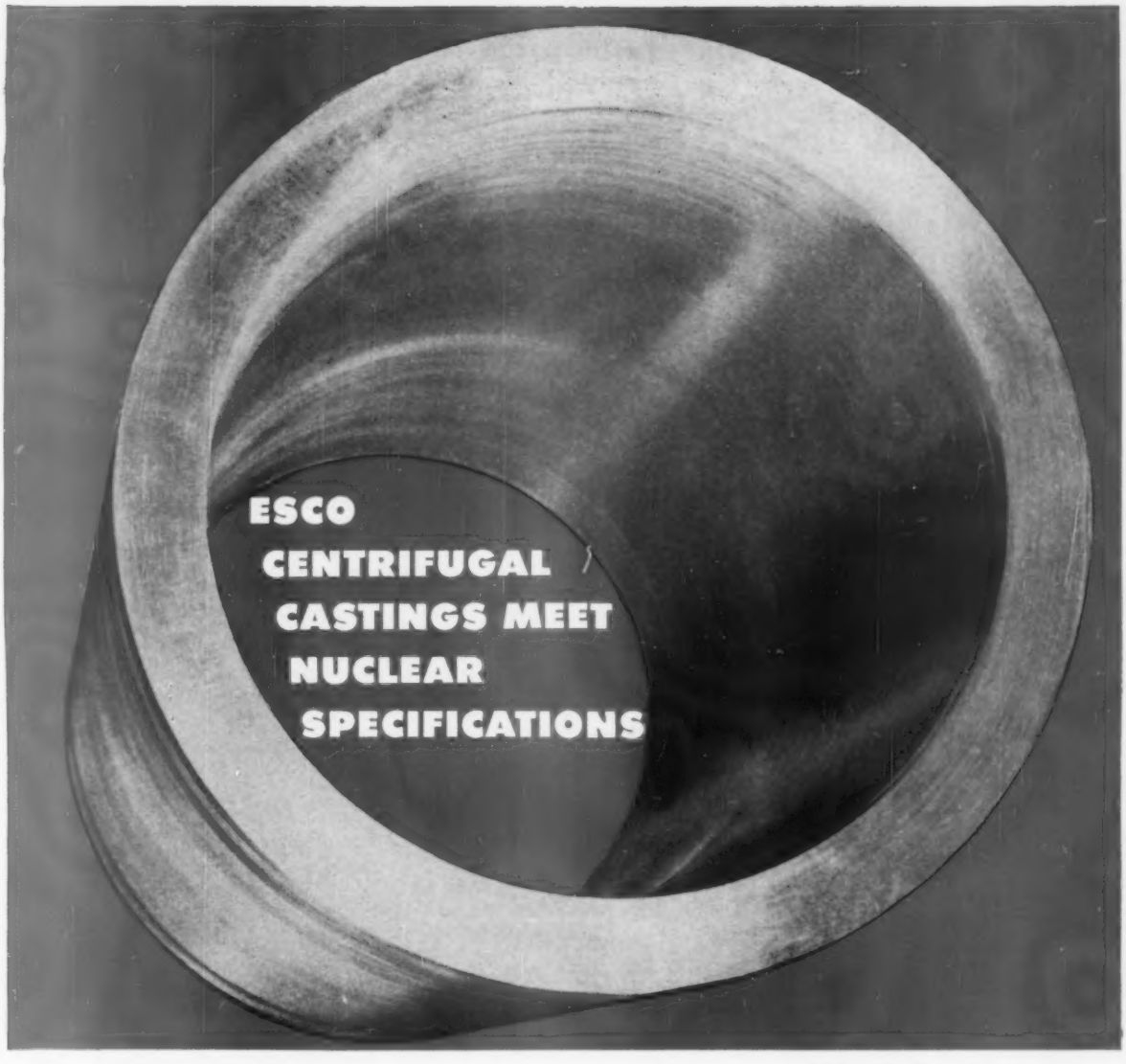


FIG. 3. INTENSITY of uranium *K*-series fluorescent radiation vs thickness of zirconium cladding. Data normalized to intensity of fluorescence from bare uranium



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INSTRUMENTATION AND MEASUREMENTS

This article starts on page 70

conducted for two reasons: successful correlation had already been obtained using the uranium *L* series, and the atomic number of aluminum was sufficiently low that the attenuation and scattering characteristics of aluminum were expected to be formidable difficulties. High scattering would prove troublesome in that the attenuation of the fluorescence radiation possibly would be compensated by the increase in scattered radiation. This prediction was confirmed—even in stainless steel, no statistically significant changes in the uranium *K* fluorescence intensity could be found for the range of cladding thickness investigated.

Scanning. A section of an actual tubular fuel element clad with Zircaloy-2, which had been visually measured at one end, was analyzed by measuring the uranium *K*-series fluorescence radiation taken at 10-deg intervals around the periphery. The two sets of measurements showed excellent correlation.

Several fuel elements were scanned in a demonstration that the technique is applicable to a continuous quality-control process. A Zircaloy-clad tubular fuel element was scanned rotationally at 1 rpm, with the data (see Fig. 4) being placed on a Brown strip recorder. The rotational scan clearly showed the eight-fold symmetry of the extrusion that had been indicated by earlier measurements. The variation in cladding thickness was of the order of 5 mils.

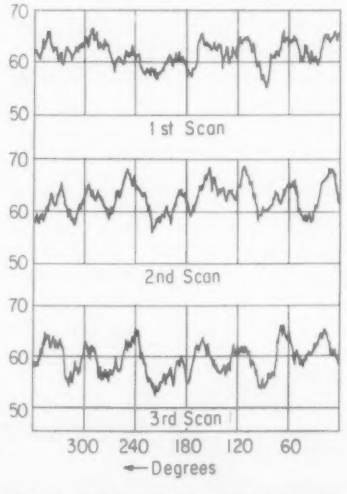

FIG. 4. ROTATIONAL SCAN of tubular fuel element

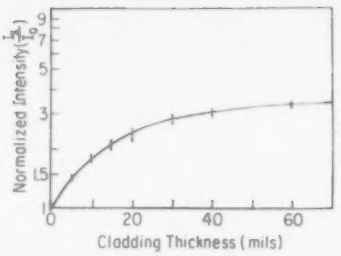

FIG. 5. SCATTERED INTENSITY low-energy photons vs thickness of type 304 stainless steel cladding

Compton Scattering Technique

The technique of cladding measurement by Compton scattering requires incident X-rays of ~100 kev. The cladding materials of lower atomic weight will absorb principally by Compton scattering, whereas the uranium base metal will absorb incident photons principally in the photoelectric mode.

The intensity of the scattered radiation from the cladding surface was measured by setting the base line of the pulse-height analyzer at the peak of the scattered spectrum and recording a series of "fixed-count" measurements for varying thicknesses of cladding material. The equipment and geometry used for this phase of the investigation was identical to that for the uranium *K*-series study. The only difference was the setting of the pulse-height-analyzer base-line voltage.

The results for stainless steel are plotted in Fig. 5. The plot is normalized to the intensity of bare uranium. Comparable results were obtained for uranium clad with aluminum. Zirconium, with a relatively higher atomic number, has an absorption coefficient that is high with respect to its scattering coefficient and, therefore, does not lend itself to analysis by this technique.

From an analysis of the data, we concluded that the cladding thickness of uranium fuel elements with 30 mils of cladding can be measured with an accuracy of 5% by the technique of Compton scattering.

* * *

The authors would like to express their appreciation to Nuclear Metals, Inc. of Cambridge, Massachusetts, which provided various fuel elements for use in the study.

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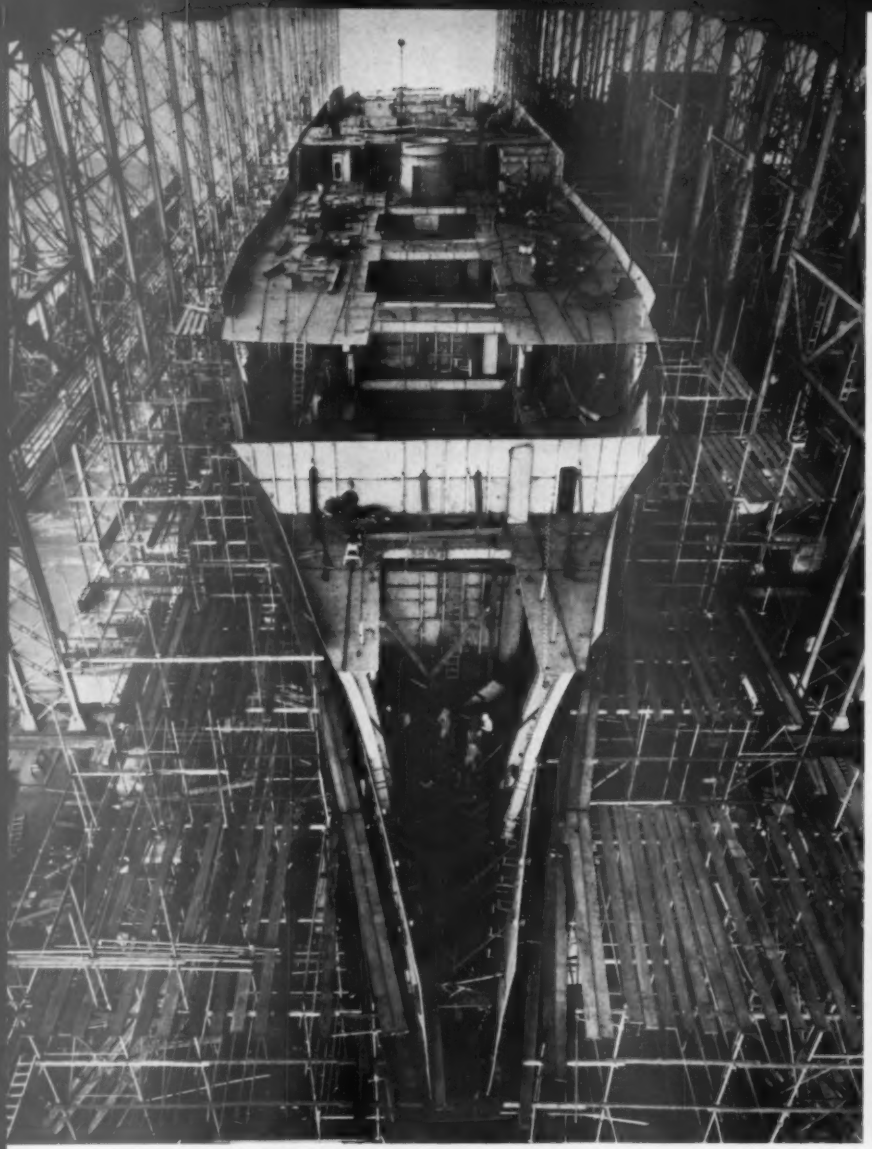
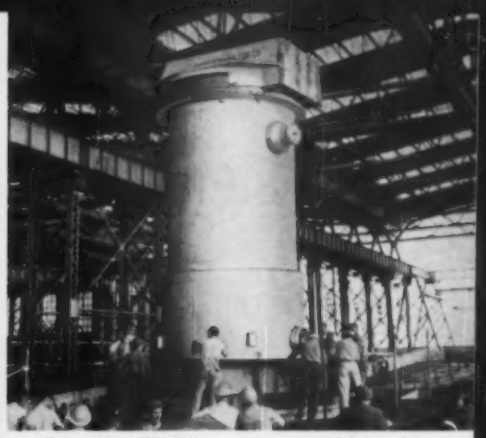
2. L. S. Birks, E. J. Brooks, H. Friedman. Fluorescent X-ray spectroscopy, *Anal. Chem.* **25**, 668 (1953)

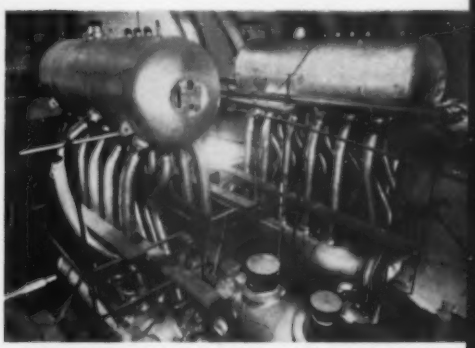


Construction of N. S. Savannah



Lowering B&W pressure vessel into ship

B&W low-enriched uranium fuel element for N. S. Savannah



B&W heat exchangers in containment vessel

A New Era Begins

This month the world's first nuclear-powered merchant ship will be launched at Camden, New Jersey. The N. S. Savannah, a joint project of the Maritime Administration and the Atomic Energy Commission, is also America's first nuclear-powered surface vessel.

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Method for Checking Energy of Accelerated Electrons

By V. A. CAMPANILE and CHARLES D. WAGNER
Shell Development Co., Emeryville, California

In using electron accelerators in radiation chemistry, it is important to have an accurate knowledge of the electron-beam energy. We are using a method that depends on the variation in electron penetration with energy. It is simple to use, yet accurate to within 0.5%.

Previous Methods

Van de Graaff accelerators presently manufactured* are equipped with generating voltmeters, which furnish a direct current proportional to the d-c potential across the accelerator tube. The calibration of these devices must be checked frequently to ensure accuracy.

For an absolute calibration, properties of the electrons themselves must be used. The currently accepted method for the 2–3-Mev range is to determine the γ,n energy threshold for bremsstrahlung on beryllium or deuterium. The electrons are absorbed in a heavy-metal target, the bremsstrahlung produced are allowed to interact with beryllium or heavy water, and the resulting neutron flux is determined by a silver or rhodium foil placed nearby.† While the method is accurate, it is tedious, for it requires a succession of carefully conducted activation experiments to note the threshold for zero neutron flux. While it is satisfactory for an initial absolute calibration, a faster method is needed for subsequent checking of the electron energy.‡

New Method

Since electron penetrating power increases approximately linearly with energy in this range, it seemed probable this property could be utilized. To explore the feasibility of this idea, an aluminum absorber of variable thickness was placed in the electron beam (Fig. 1), and the electron current, I_t, penetrating the absorber was recorded for a total beam current of 50 μa at various electron energies. Curves obtained are shown in Fig. 2.

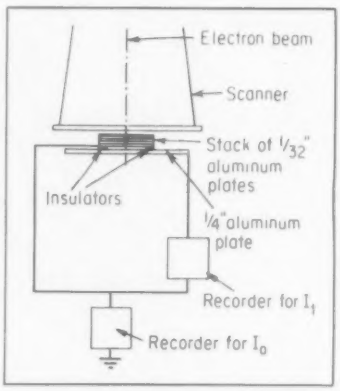


FIG. 1. VARIABLE-ABSORBER arrangement to determine relationship of electron penetrating power with energy (data plotted in Fig. 2)

With a ⅛-in. aluminum absorber, I_t/I_o is 0.6 for 3.0-Mev electrons. This ratio changes in value by 1% for a change in electron energy of 25 kev. For convenient voltage checking, an arrangement shown in Fig. 3 was adopted, utilizing a Leeds and Northrup galvanometer No. 2330-d, with a sensitivity of 0.3 μa/division. It is evident that null is attained when $I_tR_t = I_aR_a$. Greatest sensitivity is attained when the resistance of the galvanometer, R_g, is much less than R_a and R_t. The unbalance current is then equal to the change in I_t from that at balance. It is easily shown that, for a practical checking current of 100 μa, a deflection of one division corresponds to 0.3 μa change in I_t, 0.6% change in I_t/I_o, or 15,000 volts at 3 Mev.

The apparatus is simply installed and the voltage checked within a few minutes. The accuracy of the galvanometer reading is considerably greater than plus or minus one division, so that the accuracy of the measurement is better than the stability of the potential of the Van de Graaff terminal. Only the initial absolute calibration is required, plus periodic checks of the resistance values and of the linearity of the voltage-indicating system.

The apparatus is not only applicable to the Van de Graaff, but it can also be used with other accelerators if the relative beam-energy distribution is constant.

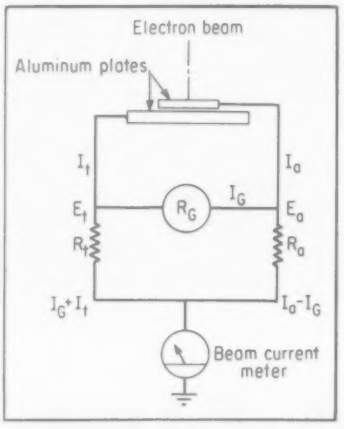


FIG. 3. CIRCUIT of partial-absorption voltage checker

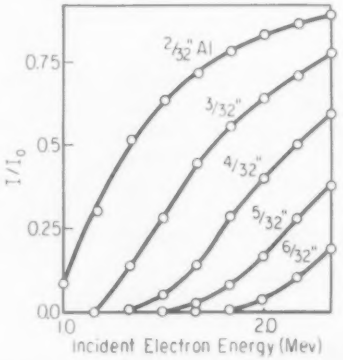
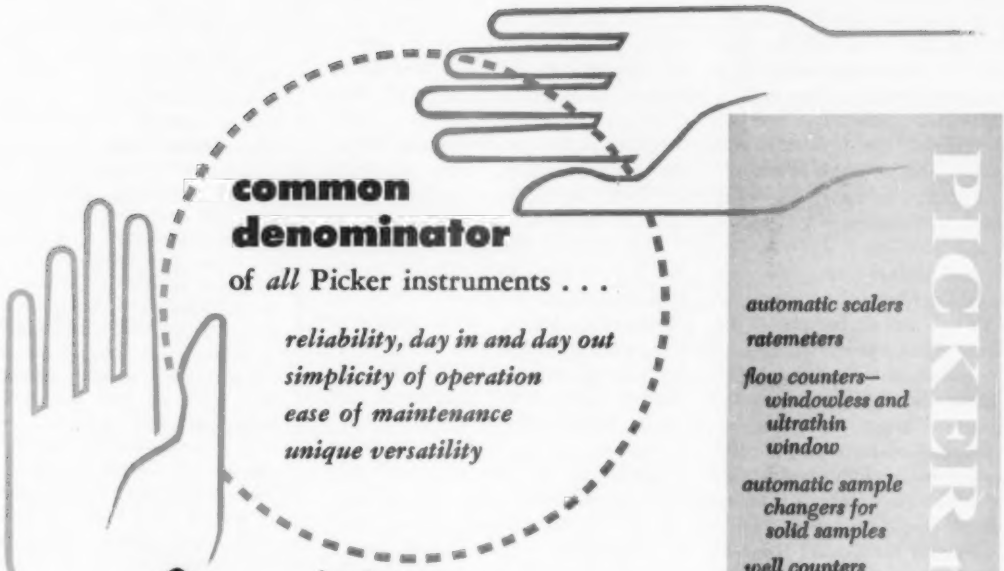


FIG. 2. I/I_o VS INCIDENT ELECTRON ENERGY for aluminum absorbers of $^2/_{32}$ to $^6/_{32}$ in.

* By High Voltage Engineering Corp., Burlington, Mass.

† The method of absolute calibration is described in detail by R. H. Schuler and A. O. Allen [*J. Chem. Phys.* **24**, 59 (1956)].

‡ It has been found unfeasible to use neutron counters in the photodisintegration-threshold method since these counters are inoperative at these very high photon fluxes.



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British Unveil Maritime Designs

The across-the-board cross-sectional look into British reactor-design capability afforded last month by the disclosure of the eight merchant ship powerplant proposals made to the Admiralty (NU, June '59, p. 25) probably surprised many on this side of the water. For it revealed Britain's private nucleonics industry as being less wedded to the gas-cooled reactor concept, and even more sophisticated in its original design ideas, than had been generally thought here on the basis of British atomic posture at the Geneva conference last September.

Only two of seven proposals by private firms (the eighth was from the U. K. Atomic Energy Authority) involved the gas-cooled concept. But these two involve not only considerable improvement on the AEA's two current advanced gas-cooled reactor projects—AGR (Advanced Gas-cooled Reactor) and HTGC (High Temperature Gas-Cooled reactor) (NU, Jan. '59, 17)—but promise earlier completion in the bargain.

Basing their design on AGR, the General Electric Co.–Simon Carves group claims to have cut capital cost of building gas-cooled plants from the $340/installed-kw of Hinkley Point, most up-to-date of the central stations under construction, to $170/kw. By switching to slightly-enriched uranium dioxide clad in stainless steel, GEC was able to raise fuel temperature to 710° C—probably 50–100° C higher than will be possible with the beryllium-clad oxide elements in AGR. Also, fuel element geometry has been radically improved: annular elements reduce the temperature gradient, leading to higher Mw/t ratings. A major consequence of these changes is a great reduction in the specific size and cost of gas-cooled reactors: GEC says its 50-Mw(e) design should not cost more than $8.4-million.

The reactor vessel is only 14 ft dia × 21 ft long, barely as big as the charge-discharge machine alone at the Hunterston station. Total weight of the entire installation is under 2,500 tons, total volume 68,000 ft³. The reactor and steam generators are placed horizontally to lower the ship's center of gravity: charge-discharge pipes are at one end, control rods and emergency access hatch at the other end of the horizontal cylindrical reactor vessel; the fuel elements are inserted horizontally in the graphite core, and four steam generators are placed outside the shield above and to either side of the reactor. The reactor can be charged and discharged under load, even at sea. Steam conditions are 600 psi, 450° C.

The GEC design is much more advanced than that of the A.E.A., which also submitted an AGR-type modified for shipboard use but much closer to the AGR prototype now building at Windscale, although development times for both are comparable. Interestingly, GEC is principal contractor to A.E.A. on the Windscale AGR.

PWR Fuel Elements in Meltdown Tests

Experiments in which PWR-type fuel assemblies were actually melted down predict that in a genuine meltdown the PWR core would (a) release less than 1% of its fission products (except for Xe and I) and (b) be 20% consumed by the zirconium-steam reaction. Mine Safety Appliances Company used a specially constructed chamber in which a 200-kw induction coil heated the subassembly specimen to its melting point in about a minute. A steam atmosphere provided the opportunity to observe the effect of the Zr-steam reaction on the Zr-clad U-Zr-alloy fuel.

In four of the meltdown runs, the center plate (of the nine fuel plates that formed a subassembly) had been irradiated slightly so that it contained small amounts of fission products (~200 mc). The major fission product released by meltdown was found to be Xenon; about 50% of the Xenon escaped. Iodine was the next most important fission product with as much as 25% escaping. For all other fission products the release was less than 1% of the total amount present in the plate.

Partial plugging of the channels with melted metal occurred in all cases; molten metal fell from the subassembly in streams rather than in droplets. [*MSA Technical Report No. 63 (October 1958)*].

SS Corrosion Resistance in Na Improves with Age

With long-term exposure to Na, stainless steel (AISI Type 316) apparently builds up a ferritic surface layer that reduces Na corrosion by a factor of three over the initial rate. In experiments with thermal convection loops circulating sodium between 1,100° F and 1,575° F, John McKee (Nuclear Development Corp. of America) has observed the corrosion rate as a function of time for 5,000 hours. He reported to the Cleveland Nuclear Congress in April that the corrosion rate at 4,000 hours of stainless-steel tabs levels off at 0.5 mg/cm² month—about ⅓ the rate at 500 hours. The reason for the improved corrosion resistance seems to be that the metal on the exposed surfaces transforms from austenite to ferrite (to a depth of about a mil), presumably because of changes in composition. This effect was masked in previous experiments which measured only the total corrosion over the test period.

UK Reactor Builder Against Goliaths

A.E.I.–John Thompson Nuclear Energy Co. [contractors for the 275-Mw(e) Berkeley station] explained at the recent Nuclear Congress in Cleveland why they don't like the 200–400-ton Goliath cranes that have become the trade marks of their three English competitors.

To erect their nuclear plants, A.E.I.–Thompson prefer a modest arrangement of four 15-ton Monotower cranes. They grant that the rate of construction is higher with a Goliath crane once the crane itself has been erected; but they hold that the time spent in putting up the Goliath crane makes the over-all construction times come out the same, so that the much greater capital expense of the Goliaths is not justified.

A.E.I.–Thompson feel so strongly about lowering capital costs that they accepted a sacrifice in thermal efficiency in the Berkeley plant to get an over-all capital-cost reduction.

At the same conference session, General Electric Co., Ltd.—contractors for the 320-Mw(e) Hunterston station

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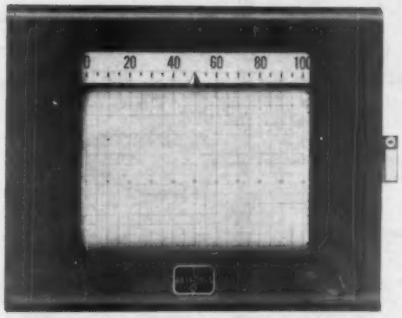

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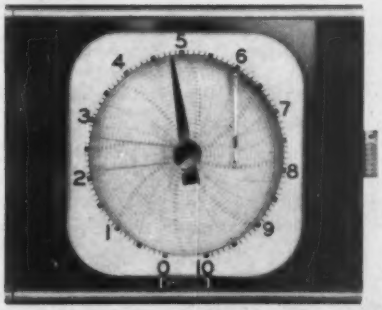

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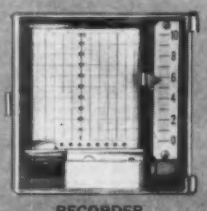

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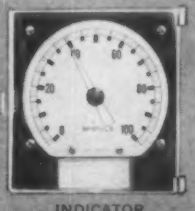

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This article starts on page 76

—told about ambitious plans to refuel and service their reactor under load. Not only will the automatic charging machine operate while the reactor is at full power, but most maintenance operations including removal and servicing of control rods and their drives will be done under full power.

Spray Evaporation Gives High Heat-Transfer Rates

Steam with water droplets dispersed within it shows promise as a new kind of reactor coolant. British workers* using an electrically heated test rig have measured heat-transfer coefficients of 5,000–10,000 Btu/hr/ft²/° F for liquid-vapor systems containing of the order of 60% by weight steam. These coefficients compare with liquid-metal heat-transfer coefficients and are some 65 times higher than pure-steam coefficients and 8 times higher than pure-water coefficients. It is not yet clear whether the heat-transfer enhancement results from the increased turbulence due to the presence of the liquid droplets or from the "flashing" of the droplets when they are carried by the turbulent eddies to the heat-transfer surfaces.

The term "spray evaporation" describes the cooling process that would occur in a power reactor—water droplets would be sprayed into saturated steam entering the core; as the droplets rise with the steam they continually evaporate, converting the reactor heat into latent heat of vaporization. At the core exit a separator removes the remaining droplets from the steam. Part of the steam is then recirculated to the core and the rest goes through a superheater to the turbine. The heat-removal process is similar to that in an ordinary boiling-water reactor except that the liquid and vapor phases are reversed—i.e., water droplets have replaced steam bubbles.

The heat-transfer tests were done at atmospheric pressure for variable total heat flux, steam quality and mass flow rate. Steam quality of 50–60% appears to give the maximum heat-transfer coefficient.

As a variation on the steam-water system, one could consider using two-component systems such as liquid sodium dispersed in helium or water dispersed in argon.

* H. R. C. Pratt, J. D. Thornton, P/1451 Geneva, 1958.

Scanning the Literature

Cross sections for neutron-induced reactions. The descriptive framework for treating nuclear reactions and current phenomenological models and methods for calculating nuclear cross sections are reviewed with particular reference to neutron-induced events at energies up to ~14 Mev. (WADC TR 58-79*)

Economics of nuclear and conventional merchant ships are compared for the period 1957–1970 using cost per unit carried and return on investment as the basis for comparison. Capital and operating costs are determined at various trade-route distances and speeds. ($4.50 from U. S. Government Printing Office, Washington 25, D. C.)

Reactor materials. Compilation (366) of book, report and journal references on the choice and properties of materials (excluding fuel materials, except where coincidental) to be used in reactors and reactor environments. (IGRL-IB/R-15; $0.81 from British Information Services, 45 Rockefeller Plaza, New York, N. Y.)

Thermal properties of Fe, Be, Ir, Rh, Pd, Pt and W. A bibliography of 416 references pertaining to heat capacty, thermal conductivity, emissivity, thermal diffusivity and thermal expansion. (WADC TR 56-423 Pt II; from Armed Services Technical Information Agency, Arlington Hall Station, Arlington 12, Va.)

High-purity materials. A catalog of suppliers of high-purity elements. (UCRL-5386; $1.25*)

Decontamination of reactors and coolant loops. A literature review on the development and selection of compatible materials and decontaminants. (HW-57642; $0.75*)

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Use of Less Expensive Rare Earths as Control Materials

By J. A. RANSOHOFF*

Much has been said and written by proponents of the use of europium as a control-rod poison. It is not uncommon in such arguments to dismiss summarily the other, more plentiful rare earths as being inadequate because of low cross section, high cross section, short life, etc. (*1, 2*). It is time they were considered more seriously as contenders.

Actually, the less illustrious, more abundant rare earths, while not quite as unique as europium, are much more competitive with, and sometimes superior to, other control-rod materials now being used. The fact that dysprosium's cross sections are lower than europium's doesn't mean that they're too low. The relative sparsity of absorbing isotopes in Gd and Sm does not necessarily mean that there are too few. And yet the fact that Eu_2O_3 costs about $800/lb does usually mean that it is too expensive. It is my intent to bring Eu, Gd, Sm, Dy and Er into proper perspective, considering their price and probable availability as well as their physical and nuclear properties.

* Mr. Ransohoff is a consulting nuclear engineer. His work on the development of uses for the rare earths in control rods has been sponsored by the Lindsay Chemical Div. of the American Potash & Chemical Corp.

Cost and Availability

When the heavy rare earths were first considered for control-rod poisons, principally by Knolls Atomic Power Laboratory and the Navy, they were extremely scarce and expensive. Eu_2O_3 was priced anywhere from $20 to several hundred dollars per gram, when it could be had at all, and even Sm_2O_3 was over $2/gm. "Lindsay mix," a crude mixture of Sm and Gd oxides, sold for about $90/lb, and the composition of every batch was different. Furthermore, not all suppliers' analyses were reliable, so that one could not always be certain that one would obtain what one had bargained for.

Times have changed. Prior to 1955, the heavy rare earths were separated commercially by means of fractional crystallization—the 1955 prices for those that were available are shown in Table 1. When the conversion to ion-exchange separations, developed at Ames, was made in 1956, the prices charged for the materials dropped to the level shown in Table 1. More recently, larger columns have been brought into production, and some of the raw-material costs have been reallocated, reducing prices of the separated rare earths to the level shown in the 1958 column of Table 1 (*3*). Note also that production capability for just one producer has risen from grams per year to the level shown in the last column.

Whether or not greater production capabilities are developed, or prices drop still further, will depend of course upon the development of a large market. Note, however, that while there has been a sizable decrease in all the rare-earth prices, Eu is still much too expensive to consider the use of say 1,000 lb for the control rods of a commercial reactor. Unless someone happens upon an ore relatively rich in Eu, or an inexpensive means of enriching, this is likely to remain the case at least until substantial markets develop for the other rare-earth poisons.

TABLE 1—Cost and Availability

Oxide	*Purity (%)*	*Cost ($/lb)*			*1958 production capability (lb)**
		1955	*1956*	*1958**	
Eu_2O_3	99	3,600	2,450	790	Several hundred
Sm_2O_3	80	Not offered		20	45,000
	99	1,850	125	45	
Gd_2O_3	80	Not offered		30	25,000
	99	900	180	90	
Dy_2O_3	99	Unavailable	6,750	50	20,000
Er_2O_3	99	Unavailable	9,000	50	8,000
Sm_2O_3 / Gd_2O_3	45	100	75	25	50,000

* Prices and production quantities are from one producer only. The efforts of other producers will affect the total production capability, and some of their prices may be different.

Nuclear Properties

Regardless of price, there are certain properties any poison must have to merit serious consideration. The physical properties of the rare earths are well known and all similar; many of their nuclear properties are defined also (see Table 2). These properties will now be considered further.

Samarium. Samarium admittedly has too few high-cross-section isotopes. However, two factors argue in its favor: (1) it is very black thermally and has a good resonance integral; (2) it is relatively inexpensive and abundant.

Gadolinium. Gadolinium has relatively little epithermal effect, but it is a good thermal absorber and has a long enough life for many power-reactor applications. Dollar for dollar, it is a competitive poison for most reactors, and, even without the aid of additional epithermal poisons, Gd can frequently provide adequate rod worth. Of course, if Gd were to be used in conjunction with some of the better epithermal absorbers, the resulting rod worth would be that much better (*4*).

Although the lifetime for Gd, even assuming a Gd^{156} cross section of zero, is adequate for many applications, it

may actually be significantly longer. Lapp did some work that indicates that Gd^{156} may have a cross section of >5,000 barns (*5*). If Gd^{156} were to have a cross section of even 1,000 b, the Gd lifetime would be approximately trebled. This cross section is important enough to be worth the little effort needed to measure it.

Erbium. Erbium has too low a thermal cross section to be of much interest by itself (*4*). However, its resonance at about 0.5 ev makes it an attractive addition to Gd to offset the latter's positive temperature effect, which results from the rapid decline of its high thermal resonance.

Erbium could also be of use as the poison in shim sections of rods for reactors with a positive, or at least no negative, temperature coefficient. The unique shape of its cross-section curve should make it temperature-sensitive in the proper direction.

Europium. Were it not for its cost, Eu would be an attractive poison. Rods constructed from it would have long life, light weight and good rod worth. However, because of its expense, Eu loadings must be kept light, and, when this is done, some of the advantages are sacrificed. For example, much of Eu's worth is undoubtedly due to the Eu^{151} resonance of 23,000 b at about 0.5 ev. A rod with a surface density of 1 gm/cm² of Eu would still absorb 90% of the thermal neutrons striking the surface after exposure to 8×10^{21} nvt. However, all of the best epithermal absorber, Eu^{151}, would have been burned out after exposure to only 4×10^{21} nvt (*6*). If the rods were scheduled to last for several core loadings, there might not be adequate rod worth to hold down the required amount of reactivity later in the expected life of the rods.

Because of its cost and properties, Eu is of interest primarily in military reactors—where cost is less of an object, fluxes may be quite high, the number and size of control rods are relatively low, and light weight and thinness are virtues. Ease of maintenance is also of paramount importance. Though it is usually not so in commercial reactors, in military systems a "hot" control rod could be a considerable nuisance. Upon exposure to 8×10^{21} n/cm,² 1 gm/cm² of Eu would have an activity of roughly 20 curies/cm² of hard gammas upon removal from the reactor and 13 c/cm² ten years later. Thus, the bottom square foot of control-rod surface might contain as much

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Dysprosium. Dysprosium was originally of interest primarily as a potential burnable poison, but it was discovered that it, like Eu, has a continuous chain of relatively high-cross-section isotopes. However, this chain of isotopes does make Dy a potentially attractive control-rod material, even more attractive than Eu for many applications.

Aside from its considerably lower cost, Dy has several apparent advantages over Eu. Its most rapidly burnable isotope, Dy^{164}, is almost a pure thermal absorber, and its daughter decays to Ho^{165}, which has several excellent resonances between 4 and 200 ev. So one might expect Dy to retain, or possibly even improve for a while, its resonance integral upon irradiation, depending of course upon the relative contributions of Dy^{161}, Dy^{162}, and Dy^{163}. Another advantage of Dy is its lack of long-lived radioactive daughters. After exposure to 8×10^{21} n/cm², a section of Dy containing 4 gm/cm² of the oxide would have an activity of hundreds of curies/gm, but activity would decay by a factor of about 100/week (*6*).

Rod Worth and Lifetime

In deciding whether or not to use rare earths in a specific reactor, two criteria are of utmost importance: (1) They must provide adequate rod worth in a control device of reasonable size and cost. (2) The poison must last long enough in the pile to provide effective control-rod lifetime. Of course the material must be fabricable and have satisfactory radiation damage resistance.

Worth. Rod-worth requirements vary from one reactor to another, of course. Russell et al. have determined relative rod worth for several of the rare earths and combinations thereof in the Dresden critical facility at Vallecitos (*4*). Some of their important values are shown in Table 3. While the relative worths may be somewhat different in different energy spectra, it is apparent that several of the rare earths, while less effective than europium for a given loading, are considerably more effective than some materials now being used. Note that Eu_2O_3, for a surface density of 0.8 gm/cm² and at a cost of about $1,300/ft², would have a rod worth of 1.20 relative to Cd. By comparison, for the same rod worth or greater, Dy_2O_3 at a surface density of 2.6 gm/cm² costs about $260/ft²; 1.7 gm/cm² of Dy_2O_3 plus 0.9 gm/cm² of Gd_2O_3 costs about $200/ft²; 1.7 gm/cm² of Gd_2O_3 plus 0.9 gm/cm² of either Er_2O_3 or Dy_2O_3 costs about $190/ft²; and 1.6 gm/cm² of Lindsay mix with 0.8 gm/cm² of Dy_2O_3 or Er_2O_3 costs about $150/ft².

TABLE 2—Physical and Nuclear Properties

			Thermal-neutron absorption cross sections	
	Density (gm/cm³)	*Melting point (° C)*	*Isotope*	*Cross section (barns)*
Sm	7.54	1,052	149	66,000
Sm_2O_3	7.43	2,350	150	unknown
			151	12,000
Gd	7.87	1,350	155	70,000
Gd_2O_3	7.41	2,350	156	unknown
			157	160,000
Er	9.06	1,500	166	unknown
Er_2O_3	8.64		167	unknown
Dy	8.57	1,485	(*15*) 161	730
Dy_2O_3	7.81	2,340	162	250
			163	160
			164	3,000
			Ho^{165}	64
Eu	5.17	826	151	9,000
Eu_2O_3	7.42	2,050	152	5,000
			153	400
			154	1,400
			155	13,000

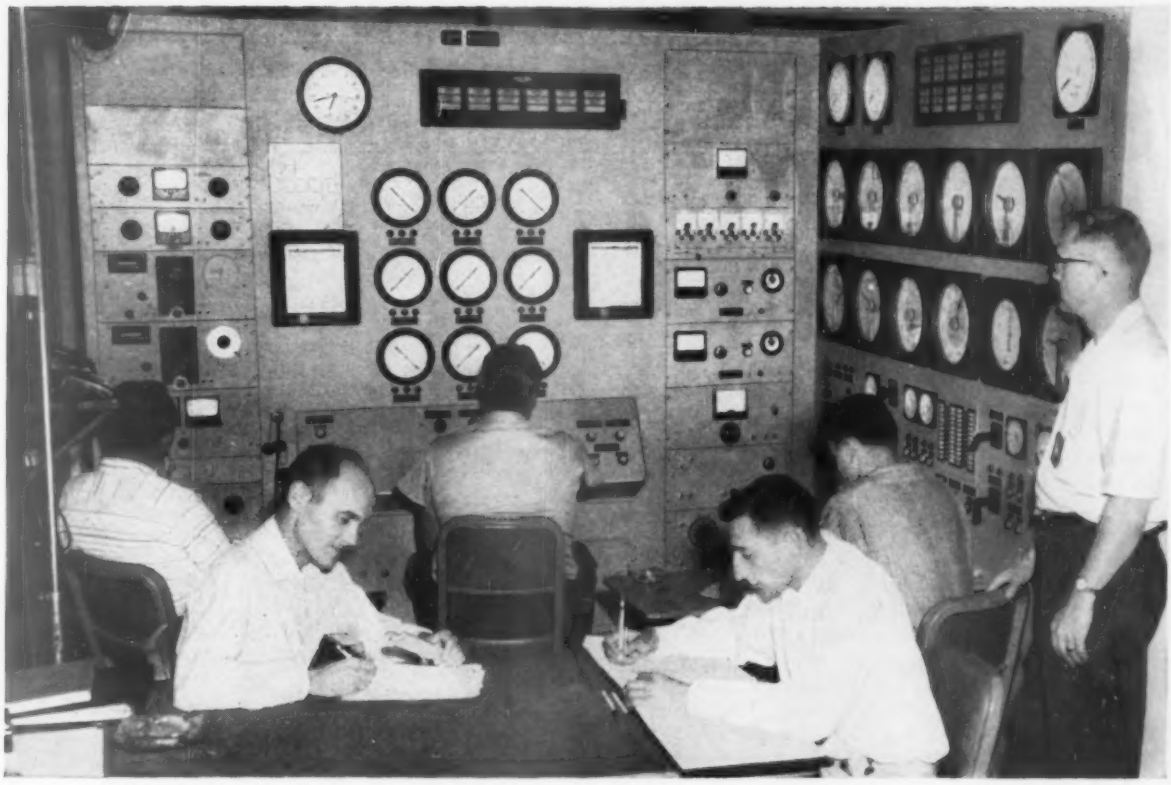
TABLE 3—Comparative Rod Worth of Rare-Earth Materials

Material	*Surface density (gm/cm²)*	*Control-rod worth corrected to ¼-cm thickness . relative to ¼-cm-thick Cd*
B steel	0.128 (boron)	1.10
Cd	2.14	1.00
Dy_2O_3	2.57	1.20
Er_2O_3	2.99	1.07
Eu_2O_3	0.77	1.20
Eu_2O_3	2.31	1.34
Gd_2O_3	2.64	1.15
Sm_2O_3	2.04	1.17
Mixed Oxides of . . .		
Dy*Eu*Dy	0.86*0.77*0.86	1.27
Eu*Dy*Eu	0.77*0.86*0.77	1.33
Dy*Gd*Dy	0.86*0.88*0.86	1.21
Gd*Dy*Gd	0.88*0.86*0.88	1.22
Gd*Er*Gd	0.88*1.0*0.88	1.20
Eu*Gd*Eu	0.77*0.88*0.77	1.35
Gd*Eu*Gd	0.88*0.77*0.88	1.27
Eu*Gd*Sm	0.77*0.88*0.68	1.29
Dy*Gd*Sm	0.86*0.88*0.68	1.22
Er*Gd*Sm	1.0*0.88*0.68	1.20

Admittedly, if extremely high rod worth for a limited surface density is required and cost is no object, higher loadings of Eu_2O_3 will yield higher rod worths than those attainable even with mixtures of other materials. However, it is worth noting that substantial increases in rod worth can be attained by adding other poisons to Eu. Particularly interesting is the fact that above a surface density of 1.5 gm/cm² Eu_2O_3, additions of Dy, Er or Gd add as much to rod worth as an equal addition of Eu.

Lifetime. After providing for adequate rod worth, poison lifetime becomes a matter of utmost importance. Consider Table 4, wherein lifetimes are listed for the various important rare earths in terms of integrated flux and years at various average fluxes. In calculating lifetime, it has been assumed for simplicity that the reactor is operated at a plant factor of 0.80, and that the number of neutrons absorbed is 1.25 times the number of thermal neutrons hitting the control rod. For purposes of Table 4, the rods are assumed to be in the form of plates, and the neutron current is taken to be ¼ of the unperturbed flux in that area. A rod is assumed "burned out" when Σ_a has been reduced to 3.0.

Most control rods are plates varying in thickness from ¼ in. to ⅜ in.



SL-1 Reactor controls for Arctic supplied by L&N

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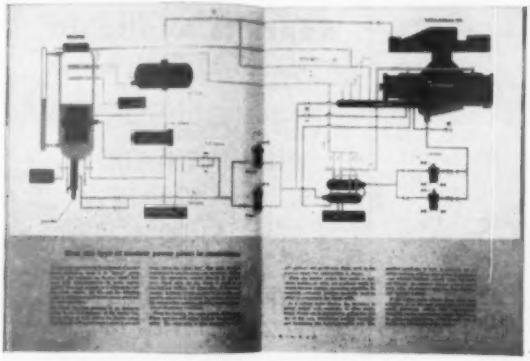

***For helpful information** on nuclear controls, ask for a copy of our publication "Nuclear Power Reactor Control Systems" by writing Nuclear Systems Group, Leeds & Northrup Co., 4936 Stenton Ave., Philadelphia 44, Pa.*

LEEDS Instruments N NORTHRUP Automatic Controls • Furnaces

Assuming that 3 gm/cm³ of rare-earth oxide can be put into a cermet (*7, 8*) and that the oxides can be easily sintered to a density of about 7 gm/cm³ (*9, 10*) and allowing about 0.050 in. for cladding, poison surface densities of 1.5–4.0 gm/cm² can be considered. Note that there are few moderate-flux reactors for which even Sm-Gd mix would not provide adequate control-rod lifetime, even for rods exposed to the maximum flux (assuming max/avg = 1.5). Also note that Dy would more than suffice even for high-flux reactors, if indeed it proves feasible to use sintered-oxide plates of the poison. Note again the difference in materials cost between the more available rare earths and europium.

Actually, reactors that have rods either most of the way in or all the way out would get much longer life from their rods than shown in the table. Furthermore, except in cases where rod worth is very important, it is not necessary to have the tops of rods loaded as heavily as the lower portions; so the average cost per square foot could be somewhat lower than cited. In short, although Table 4 is extremely pessimistic, both Dy- and Gd-based mixtures of rare earths look feasible from the standpoint of performing satisfactorily for adequate lifetimes at reasonable costs.

Corrosion, Radiation Damage

From Tables 3 and 4 it can be seen that if one is to attain really long irradiation lifetimes at high rod worths for thin control rods using the less expensive rare earths, higher loadings than attainable using cermets must be achieved. In applications where corrosion or swelling aren't problems, sintered oxides, clad and supported in a stainless steel or some other material, should be satisfactory. For water systems, however, additional work is required to show that the sintered oxide will behave satisfactorily in the event of even a pinhole leak. The partially sintered, low-density oxides crumble when exposed to 300° C water for a few hundred hours (*11, 12*). Also, preliminary tests show that even some of the high-density oxides made by sintering at higher temperatures are attacked by water. Therefore, considerable importance must be attached to work being performed on cermets with higher oxide contents.

TABLE 4—Rare-Earth Loadings Required for Minimum Rod Life

Average flux	*Minimum rod lifetime (yr)*						
$8 \times 10^{12} \rightarrow$	*3.7*	*7.5*	*15*	*22*			
$2 \times 10^{13} \rightarrow$	*1.5*	*3*	*6*	*9*	*18*	*27*	
$6 \times 10^{13} \rightarrow$	*0.5*	*1*	*2*	*3*	*6*	*9*	*12*
	↓	↓	↓	↓	↓	↓	↓
	Absorbed flux (10^{20} n/cm²)						
	5	*10*	*20*	*30*	*60*	*90*	*120*

Upper line: Required surface density (gm/cm³)
Lower line: Cost ($/ft² of control-rod area)

Oxides							
45% Gd_2O_3, 45% Sm_2O_3	0.8	1.6	3.2	4.8			
	$40	$80	$150	$240			
80% Gd_2O_3, 10% Sm_2O_3	0.6	1.2	2.4	3.6			
	$36	$72	$144	$216			
80% Sm_2O_3, 10% Gd_2O_3	1.1	2.2	4.4				
	$44	$88	$176				
Dy_2O_3*	1.2	1.5	1.8	2.2	2.8	3.3	4.1
	$120	$150	$180	$220	$280	$330	$410
Eu_2O_3*	0.35	0.48	0.63	0.70	1.0	1.3	1.6
	$560	$970	$1,000	$1,120	$1,600	$2,080	$2,560

* Dy and Eu lifetime calculations are estimated from calculations performed by the Ford Instrument Co. for plates being bombarded from one side.

The radiation problem for rare-earth-oxide cermets does not appear serious. This is not yet so with regard to the sintered oxides, although there doesn't seem to be any reason to expect a great amount of damage.

There has been no effort here to argue that the less expensive rare earths should be used in lieu of other materials —that would get too involved, since reactor requirements are so diverse. Nevertheless, it would behoove all reactor designers to compare other materials considered or being used with the less expensive of the rare earths from the standpoints of both cost and performanee. Also, potential control-rod manufacturers might consider the production of rare-earth control rods on the premise that a degree of standardization now unknown may be attainable.

* * *

The author is particularly grateful to Dr. Russell and the General Electric Co. for making their data and analysis available in advance of publication and to the Ford Instrument Co. for making available a portion of their studies on the burnup of control-element materials.

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Escape of Virgin Neutrons

By R. KLADNIK
Institute "J. Stefan," Ljubljana, Yugoslavia

In reactor-shielding calculations one has to determine the flux of virgin neutrons emitted by the reactor core. An analogous problem must be solved in calculations of the fast-fission factor. In both cases the problem can be reduced to determine the average probability P that a neutron will collide before it escapes from a cylindrical volume of infinite length. We show how P can be represented by a convergent series for a general source distribution of virgin neutrons. The series formulation of P is convenient for the problems mentioned as well as for others that require a knowledge of P, such as the degradation of the energy spectrum of neutrons born in a given source by the source material itself.

Calculating the collision probability P is essentially a geometrical problem and has already been solved for the cases of uniform (*1*, *2*) and general (*3*) distributions of virgin neutrons. The previous authors have used the method of numerical integration in connection with functions Ki_n (*4*). Here we will describe a more straightforward approach that expresses P as a suitable convergent series to avoid the numerical-integration method.

The probability of collision for a neutron born at a place r ($r = xR$, where R is the radius of the infinitely long cylinder and x is a dimensionless quantity less than 1) is

$$P(x) = 1 - (1/\pi)\int_0^{\pi} d\varphi \int_0^{\pi/2} \sin\delta \exp\{-(y/\sin\delta)[(1 - x^2\sin^2\varphi)^{1/2} - x\cos\varphi]\}\, d\delta$$

where the dimensionless quantity y stands for ΣR (Σ = macroscopic cross section for collision).

We need the average of $P(x)$ over the source distribution $\Phi(x)$ of virgin neutrons. In most cases this distribution is axially symmetric, say

$$\Phi(x) = \sum_{n=0}^{\infty} g_n x^{2n}$$

The average probability has the form

$$P = 1 - \sum_n h_n Q_n$$

$$h_n = g_n \Big/ \Big[\sum_n g_n/(2n+2)\Big]$$

$$Q_n = (1/\pi)\int_0^{\pi} d\varphi \int_0^{\pi/2} \sin\delta\, d\delta \int_0^1 x^{2n} \exp\{-(y/\sin\delta)[(1 - x^2\sin^2\varphi)^{1/2} - x\cos\varphi]\}\, x\, dx$$

The triple integral was solved by the aid of the function $f(u)$:

$$f(u) = \int_0^{\pi/2} \sin\delta \exp(-u/\sin\delta)\, d\delta$$

From the differential equation for $f(u)$, we obtain a solution in terms of the modified Bessel function of the second kind $K_0(z)$, which we can then expand. We observe that $f(u)$ differs from the function K_1 (*4*) only by a linear term.

TABLE 1—A_{nm}, B_{nm} and C_n Coefficients

$n\rightarrow$ / $\downarrow m$	0	1	2	3	4
			$A_{nm} \times 10^{m+1}$		
0	3.41483	1.60326	1.03410	0.75994	0.599633
1	2.67208	1.47914	1.03235	0.79464	0.646416
2	1.94132	1.22442	0.90405	0.71847	0.596691
3	0.91288	0.62726	0.481889	0.392164	0.330930
4	0.292438	0.213201	0.168821	0.140022	0.119725
			$B_{nm} \times 10^{m+1}$		
0	2.50000	1.25000	0.833333	0.625000	0.500000
1	2.08333	1.21528	0.868056	0.677083	0.555556
2	1.30208	0.84635	0.633681	0.507812	0.424107
3	0.542535	0.379774	0.294519	0.241096	0.204281
4	0.158239	0.116796	0.093113	0.077572	0.066537
C_n	0.666667	0.311111	0.199365	0.145669	0.114372

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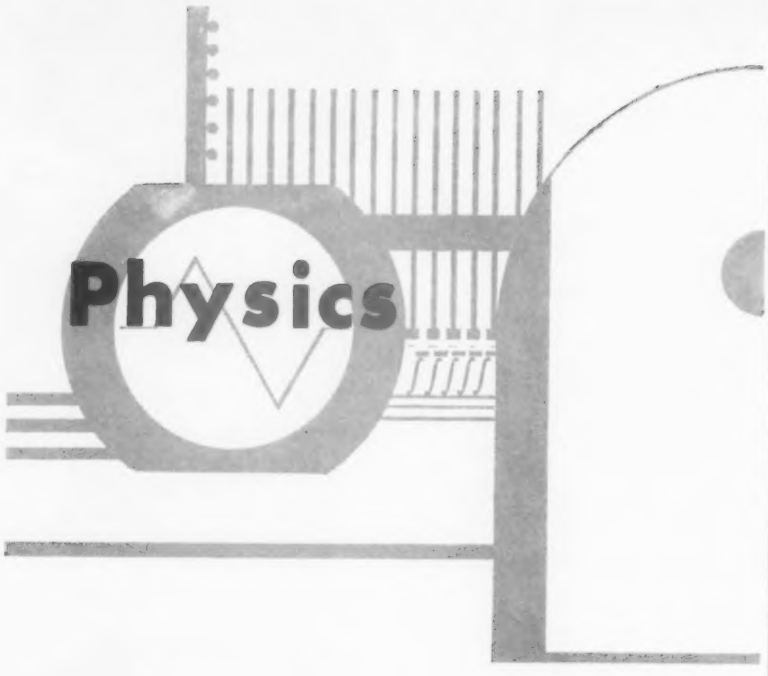

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$$f(u) = 1 - (\pi/2)u + \int_0^u dv \int_0^v K_0(z)\,dz$$
$$= 1 - (\pi/2)u + \sum_{m=0}^{\infty} u^{2m+2}(a_m - b_m \log u)$$

with coefficients

$$b_m = [2^{2m}(m!)^2(2m+1)(2m+2)]^{-1}$$
$$a_m = b_m[1/(2m+1) + 1/(2m+2) + \log 2 + \psi(m+1)]$$
$$\psi(m+1) = -\gamma + 1/1 + 1/2 + \cdots + 1/m, \text{ if } m > 0,$$
$$\psi(1) = -\gamma = -0.57721566$$

Using $f(u)$ the form of Q_n is reduced to

$$Q_n = (1/\pi)\int_0^{\pi} d\varphi \int_0^1 x^{2n} f[y][(1 - x^2 \sin^2\varphi)^{1/2} - x\cos\varphi]\,|x\,dx$$
$$= 1/(2n+2) - P_n$$

$$P_n = C_n y - \sum_m y^{2m+2}(A_{nm} - B_{nm}\log y)$$

$$C_n = (1/2)\sum_{k=0}^{n}\binom{n}{k}\frac{(k+1)!\,\Gamma(n-k+1/2)}{(2k+1)\Gamma(n+5/2)}$$

$$A_{nm} = a_m\alpha_{nm} + b_m\beta_{nm} \qquad B_{nm} = b_m\alpha_{nm}$$

$$\alpha_{nm} = \sum_{k=0}^{m}\sum_{r=0}^{m-k}\binom{m}{k}\binom{m-k}{r}\frac{2^{k-1}\Gamma(l+1/2)}{\pi^{1/2}(l+1)!}\left[\frac{(1-s)(l+1)}{n+l+r+1} + \frac{s(l+1/2)}{n+l+r+2}\right]$$

$$\beta_{nm} = \sum_{k=0}^{m}\sum_{r=0}^{m-k}\binom{m}{k}\binom{m-k}{r}\frac{(-1)^r}{4}\sum_{p=0}^{l}\left\{\frac{2\left(\frac{k}{r}\right)!}{(k-2p)(n+k+r-p+1)} - \frac{\left(\frac{k+1}{r}\right)}{(k-2p+1)(n+k+r-p+1)}\right\}$$

The ultimate form of the average probability is

$$P = \sum_n h_n P_n$$

which is useful for flattened distributions. But in reactor-shielding design the preferred expression is

TABLE 2—Comparison of Methods

		P	
R(cm)	$y = \Sigma R$	*Num. integr.*	*Series*
1	0.20343	0.2096	0.20982
2	0.40686	0.3543	0.35247
3	0.61029	0.4566	0.45684
4	0.81372	0.5368	0.53628

$$P = Cy - \sum_m y^{2m+2}(A_m - B_m \log y)$$

where the coefficients C, A_m and B_m represent the averages of C_n, A_{nm} and B_{nm} over the distribution $\Phi(x)$:

$$C = \sum_n h_n C_n \qquad A_m = \sum_n h_n A_{nm}$$

$$B_m = \sum_n h_n B_{nm}$$

Before using this method one has to evaluate numerically the constants C_n, A_{nm} and B_{nm} for different values of n, m. The number of n terms which are to be taken into account to get the desired accuracy depends on the distribution $\Phi(x)$. For typical distributions, n terms up to $n = 4$ will give an accuracy of more than 0.01%.

The m terms depend on the dimensionless quantity $y = \Sigma R$. If y is less than 1, two terms ($m = 0, 1$) will give the result accurate to about 0.05%. For y of several units, 5–7 m terms give the same accuracy.

In Table 1 coefficients C_n, A_{nm} and B_{nm} are given for indexes n, m up to 4.

For a uniform distribution: $C = 2C_0$, $A_m = 2A_{0m}$, $B_m = 2B_{0m}$. The approximate expression for P is then

$$P = \tfrac{4}{3}y - (0.68297 - 0.5 \log y)y^2 - (5.34416 - 4.16667 \log y)10^{-2}y^4$$

which is accurate to more than 0.05% if y is less than 1. An additional term ($m = 2$) will raise the accuracy up to about six decimal places.

In Table 2 the resultant average probability P obtained by the series method is compared with P obtained by the numerical-integration method (*2*) for a natural-uranium rod. The integration method is seen to be low by about 5–10%.

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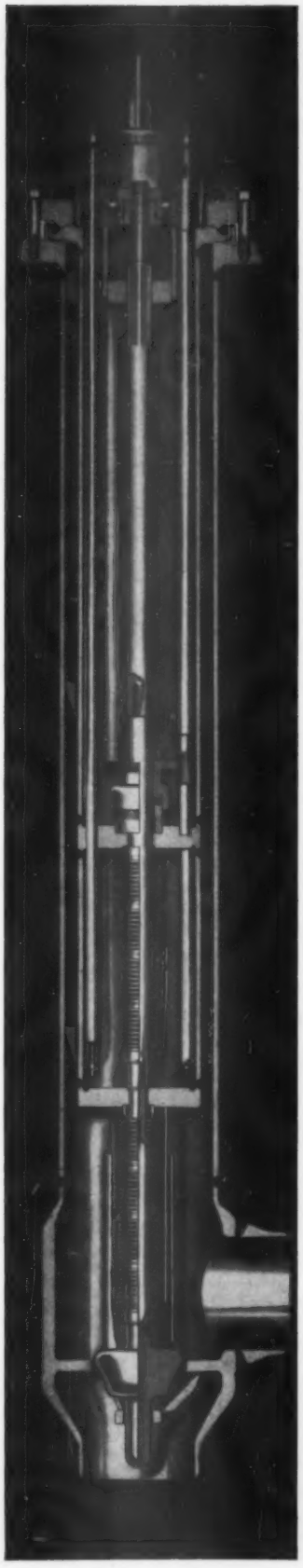

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Survey of Gamma Facilities in U. S. and Canada—an Updating

The following table brings up to date the list of industrial gamma facilities that we published a year ago (NU, July '58, p. 108). Together the two lists describe all of the industrial gamma facilities of the U. S. and most of those of Canada as they exist today.

The NUCLEONICS card file of gamma facilities is kept continuously up to date. New cards are added as we hear of new facilities; changes are entered as we hear them. In addition we have asked each of the facilities that was listed a year ago whether there should be any change in its listing. Only one change was called to our attention; a boldface line identifies this change in the present table. Information about General Electric's ANP facility in Cincinnati has been hard to get because of security regulations. Otherwise the combined list is complete and accurate to the best of our knowledge.

* * *

Miss Leida Blanco of the NUCLEONICS *staff receives credit for most of the gathering and tabulation of the data.*

Gamma-Facility Characteristics—Answers to a NUCLEONICS Questionnaire

Facility	*Location*	*Source strength, date (Curies of Co^{60} except as otherwise noted)*		*Maximum dose rate (10^6 r/hr)*	*Maximum volume (ft^3)*	*Public use?*	*Clearance required?*	*Classified experiments?*	*Personnel, policy, facilities**
New Listings									
Admiral Corp.	Chicago, Ill.	20,000	Jan. '57	0.2	300	Yes	No	Yes	PCWML
Aerojet-General Corp	Azusa, Calif	10,000	Dec '58	~1	0.25†	No	Yes	Yes	—
General Electric Co. (Gen'l Eng'g Lab.)	Schenectady, N. Y.	10,000	Jan. '59	0.46	2,000	Yes	No	Yes	PCWTL
Lockheed Aircraft Corp	Dawsonville, Ga.	(Fuel elements)		~0.1	—	No‡	Yes	Yes	PC
Southern Research Inst.	Birmingham, Ala.	790	Aug. '57	0.3	—	Yes	No	Yes	PCOM
State-Federal Screwworm Eradication Program	Sebring, Fla.	3,600‖	Nov. '58	0.05	0.098	No	No	No	MB
Union College	Schenectady, N. Y.	1,120	May '58	0.4	0.01	No	No	No	PCLR
U. S. Dept. of Agriculture§	New Orleans, La.	1,000	June '57	0.7	0.28	Yes	No	No	PCWR
Univ. of Denver	Denver, Colo.	2,000	June' 59	0.5	0.21	Yes	No	Yes	PCBLR
Univ. of Georgia	Athens, Ga.	145	Dec. '57	0.044	8.6×10^{-4}	No	No	No	P
Univ. of Florida	Gainesville, Fla.								
(College of Engineering)		835	April '58	0.45	0.0112	Yes	No	No	PC
(Agricultural Experimental Station)		6,400	May '58	~0.15	~0.25	Yes	No	No	PC
Univ. of Louisville	Louisville, Ky.	1,100	Aug. '58	0.313	0.004	Yes	No	No	PCR
Univ. of Minnesota	Minneapolis, Minn.	2,000	Oct. '57	1.2	1,500	Yes	No	No	PCWMLR
Univ. of Vermont	Burlington, Vt.	1,017	April '58	0.345	400	Yes	No	No	PCWT
Canadian Facilities									
Atomic Energy of Canada Ltd. (Irradiation cell)	Ottawa, Ont.	3,750	Jan. '59	0.35	0.13	Yes	No	No	PCBLR
Defense Research Board, Defense Research Chemical Laboratories	Ottawa, Ont.	1,500	1958	0.07	—	No	Yes	Yes	PW
Univ. of Saskatchewan	Saskatoon, Sask.								
(Source 1)		90	Jan. '58	0.1	70	No	No	No	PCOLR
(Source 2)		1,100	July '59	0.1	0.15	No	No	No	PCOLR
Changed Listings									
B. F. Goodrich	Brecksville, Ohio								
(WADC)		1,085	June '58	0.435	0.017	No	No	No	MLR
(BFG)		1,600¶		~0.28	0.35	No	No	No	MLR

* P = personnel to conduct experiments, C = contract research, W = viewing window, T = closed-circuit television, O = other viewing equipment, M = manipulators, B = conveyor, L = liquid-flow equipment, R = refrigeration equipment.

† Volume in zone receiving highest dose rate. Several other volumes also available.

‡ Available to government subcontractors.

‖ 6 Co^{60} units varying from 450 to 660 curies.

§ Southern Utilization Research and Development Division.

¶ Presently being installed.

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Is it true that an early experiment by the inventor of radiotracing, George Hevesy, was designed to prove that his landlady served the same food too often? Yes! Here's the story:

DEAR SIR:

Great efforts are made today to conserve food by making use of heavy radiation doses. My landlady of 48 years ago mastered this art without making use of any type of radiation. She managed to serve the remains of the Sunday meat pie all the week through.

In the long run this was found to be very trying by her guests. When I tried to induce her to exercise her faculty of food conservation with some discretion, she became very indignant and pretended that she did not avail herself at all of the remains of the Sunday pie.

The coming Sunday, in an unguarded moment, I added some active deposit of thorium to the freshly prepared pie, and on the following Wednesday, with the aid of an electroscope, I demonstrated to the landlady the presence of the active material in the "soufflé."

This episode is sometimes mentioned as the first tracer experiment. It was, however, just a radioactive measurement like many hundreds done before. In what I call tracer work we label an atomic species by adding, for example, a radioactive isotope of the same species and follow the paths of the atoms themselves by making use of the radioactive measurement. This type of experiment was first carried out two years after the pie incident. I did it jointly with my late friend Paneth at the Vienna Institute of Radium Research.

In this connection I wish to mention another episode. A few months after carrying out the first atom-tracing experiment I happened to assist the late ingenious physicist Moseley—killed in the First World War—in putting up the first X-ray spectrograph ever constructed. At this occasion we were indulging in a cup of tea in Rutherford's laboratory at Manchester. We spoke about the application of tracers, and I remarked that my ardent wish was to follow the path of the water molecules in the cup of tea I was just enjoying. That this wish, which Moseley considered hopeless and entirely Utopian, could be fulfilled 20 years later without difficulty was due to Urey's discovery of heavy water.

—G. HEVESY

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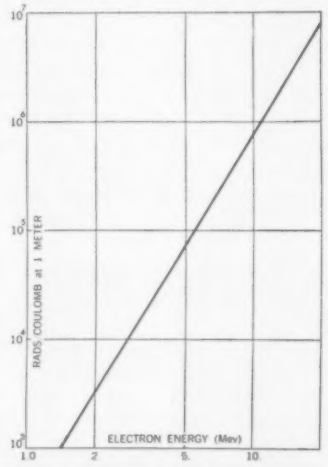
Particle Accelerators at the Research Frontier

The needs of science for charged particles in the nuclear binding-energy range continue to create dynamic interest in Van de Graaff and microwave linear accelerators. Uses for higher energy, greater intensity, and more exacting specifications of stability and pulsing are not clearly known, but consideration of attainable accelerator performance may stimulate action on research programs lying dormant for lack of appropriate apparatus. The advanced characteristics here outlined can be contemplated now, due to recent technical advances in the design of accelerator components.

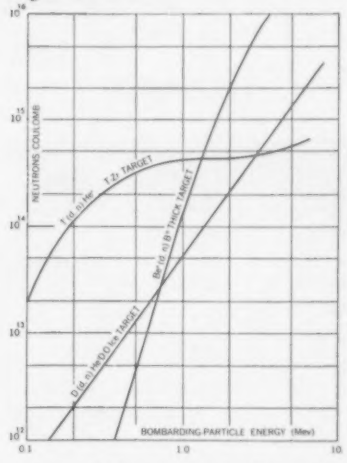
Energy: The tandem Van de Graaff has already demonstrated the availability of 45-Mev oxygen ions. By utilizing 3- or 4-stage ion-exchange and acceleration systems, heavy ions in the 100-Mev realm are conceivable. The normal Van de Graaff criteria of energy-homogeneity and low dispersion would be maintained.

The new modular design concept for the microwave linear accelerator extends the availability of high-energy electron beams to hundreds of Mev, limited primarily by budgetary considerations. Microwave power tubes and flexible design techniques can now be utilized to provide more versatile laboratory apparatus.



X-ray intensity versus bombarding energy.

Intensity: Electron or ion-beam currents in the one-ampere range, at a few Mev, can now be considered seriously. Pulsed beams with these instantaneous intensities are closer to realization than continuous beams of the same order of magnitudes.



Neutron yields versus bombarding energy.

The x-ray and neutron outputs from these beams are indeed heroic.

X-rays — millions of rads per minute at a few centimeters distance.

Neutrons — 10^{15} neutrons per second, from a "point" source.

Pulsing: New techniques enable Van de Graaffs to be pulsed from a few millimicroseconds up to a millisecond. Instantaneous intensities as described above make feasible the consideration of hundreds of rads per pulse, or more than 10^{11} neutrons per burst.

Energy Stability: It is now possible to consider stabilizing systems to a limit imposed primarily by the thermal motion of nuclear targets. With little effort, continuous particle-energy stabilities of a few tens of electron-volts can be provided.

Among the research fields in which these particle-accelerator characteristics may make a considerable contribution, are: nuclear physics, biology, solid-state, radiation damage, plasma physics, ignition of thermonuclear systems, and space-environment studies.

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Photon Activation Measures Oxygen, Carbon in Beryllium

By D. B. BEARD,* R. G. JOHNSON and W. G. BRADSHAW
Lockheed Aircraft Co., Palo Alto, California

Analysis of trace amounts of oxygen and carbon in beryllium is difficult, but there is a real need for it. We have developed a photon-activation method capable of recognizing about 1 ppm of oxygen or carbon in beryllium when other impurities are negligible. By making use of the half-lives of different activation products one can readily measure several impurities at once.

We irradiate our samples in a bremsstrahlung beam from the Stanford linear accelerator operating at 40 Mev. Then we count positron-annihilation photons and analyze the counting-rate curve to recognize oxygen, carbon and a nitrogen-copper-iron trio.

Our method has a higher sensitivity than is presently attainable by any other technique and it offers an absolute standard by which simpler and more generally available techniques can be evaluated. The method offers further advantages in being nondestructive and enabling simultaneous determination of oxygen and carbon.

Need for a Method

Programs for development of ductile beryllium need a precise method for determination of trace impurities such as carbon and particularly oxygen. Brittleness now encountered in beryllium is believed to be associated with these impurities in the crystal structure and at grain boundaries.

Research studies in the purification of beryllium, including such methods as electron-beam melting, vacuum distillation, and zone-melt refining, show promise of producing very high purity material. However, no techniques have been available to determine concentrations of several parts per million of oxygen and carbon in beryllium.

A recent survey of possible assay methods (*1*) heightened our interest in radioactivation analysis (*2*). The analysis of trace oxygen in beryllium by customary techniques is particularly difficult because of the high thermal and chemical stability of the oxide. The method ordinarily used—volatilization of the metal as $BeCl_2$ leaving a residue of BeO (*3*)—is suitable for large concentrations of oxygen. By use of large samples the technique has been refined so that it has reasonable reproducibility ($\pm 10\%$) at 350 ppm oxygen (*4*). The method suffers from drawbacks, however, in that it determines only oxygen, is subject to interference from metallic impurities and destroys large quantities of sample material.

Vacuum fusion, another standard technique often used for determining trace oxygen, nitrogen and hydrogen in metals, has been applied to beryllium analysis (*5*, *6*), but the high vapor pressure of beryllium metal and the high thermodynamic stability of BeO make this technique difficult to use unless special precautions are taken. Moreover, neither technique has been accurately evaluated because of a lack of suitable standards.

Photon Activation

The most appropriate type of activation for this kind of oxygen analysis is with photons. Charged-particle activation would be inaccurate because of surface contaminants, and oxygen has a capture cross section that is much too small for thermal-neutron activation analysis.

[NOTE ADDED IN PROOF: Fast neutron analysis for 200–4,000 ppm by weight of oxygen in beryllium has been reported recently (R. F. Coleman, J. R. Perkin, *Analyst* **84**, 233, 1959). This method is more susceptible to impurities than photon activation.]

Photon activation of small amounts of oxygen has previously been successful to an estimated sensitivity of one part per thousand (*7*). The method uses a 24-Mev betatron yielding 2 r/sec and direct positron counting in organic and metallic samples. By varying the betatron energy carbon, nitrogen and oxygen concentrations were determined separately because of their differing photoneutron thresholds. There are objections to applying the method for trace amounts of oxygen and carbon in beryllium in that (a) thin samples must be used for the beta rays to reach the detector, (*b*) the method fails to separate positron activity from the considerable background to be expected from products activated by photoprotons and photoneutrons from beryllium. (Beryllium has a photoneutron cross section ten times that of oxygen. Being up to 10^6 times more plentiful, it yields up to 10^7 neutrons for every oxygen activation.)

Photons and Positrons

Our method consists of irradiating the beryllium sample in a bremsstrahlung beam and counting annihilation photons from the positron activity of O^{15} and C^{11}. We use coincidence counting and pulse-height discrimination.

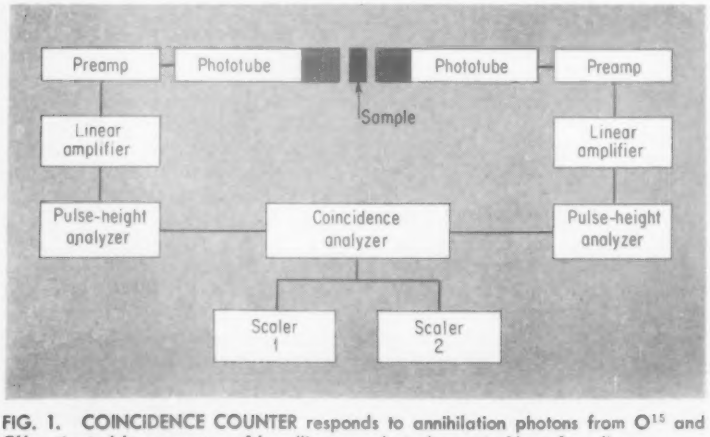

FIG. 1. COINCIDENCE COUNTER responds to annihilation photons from O^{15} and C^{11} activated by exposure of beryllium sample to bremsstrahlung from linac

* PRESENT ADDRESS: Univ. of California, Davis, Calif.

Bremsstrahlung comes from a 1-mm lead radiator in the 0.15-μa, 40-Mev electron beam. The beryllium sample in a Lucite holder is placed in contact with the radiator. Activating photons must be of only moderate energy (~40-Mev max) or background from other photoprocesses may make detection difficult. About a minute is required to transfer the sample from target area to counting area.

The counting apparatus is shown in Fig. 1. Two sodium-iodide crystals (4-in. diameter, 4 in. long) detect the 0.511-Mev annihilation photons. The crystals are mounted on 5-in.-diameter Du Mont 6364 photomultipliers. Pulses from each photomultiplier are amplified linearly, and the output from a differential or integral pulse-height discriminator at each amplifier is fed into a coincidence discriminator with a 2-μsec resolving time. Either of two scalers records the output from the coincidence discriminator. They are used alternatively in 30-sec intervals so that one count can be recorded while the next is being accumulated. Energy calibration of the pulse-height discriminators is obtained by observing annihilation radiation from a Na^{22} source.

Sensitivity

One can compute the counting rate to be expected from a known amount of oxygen in irradiated samples (*2*). Parameters involved include the bremsstrahlung spectrum from 40-Mev electrons (*8*), density of O^{16} atoms, γ,n cross section of O^{16} (11.3 millibarns for 24-Mev photons), O^{15} half-life (2.05 min) and counting efficiency (~50%). Our computations indicate that we should get 5,100 cps from one sample; the actual counting rate was 5,500 cps.

Assuming a target thickness of 0.1 cm, we integrate numerically over the photon spectrum using the photoneutron cross section reported by Strauch (*9*) and find an expected oxygen activation of 4.4×10^{-28} activation per accelerator electron per oxygen atom. For the 9×10^{11}-electron/sec beam of the linear accelerator we used, the expected activation rate is 4.0×10^{-16} activations per second per oxygen atom. Thus we anticipate an initial counting rate of $4.0 \times 10^{-16}\epsilon$ cps/oxygen atom from long bombardment times, where ϵ is detector efficiency. Similar counting rates have been estimated for the more generally available 24-Mev Allis-Chalmers beta-

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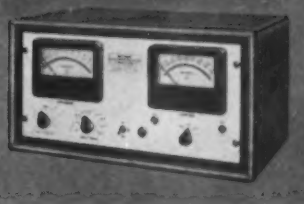

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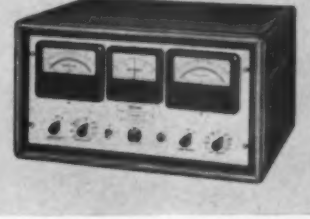

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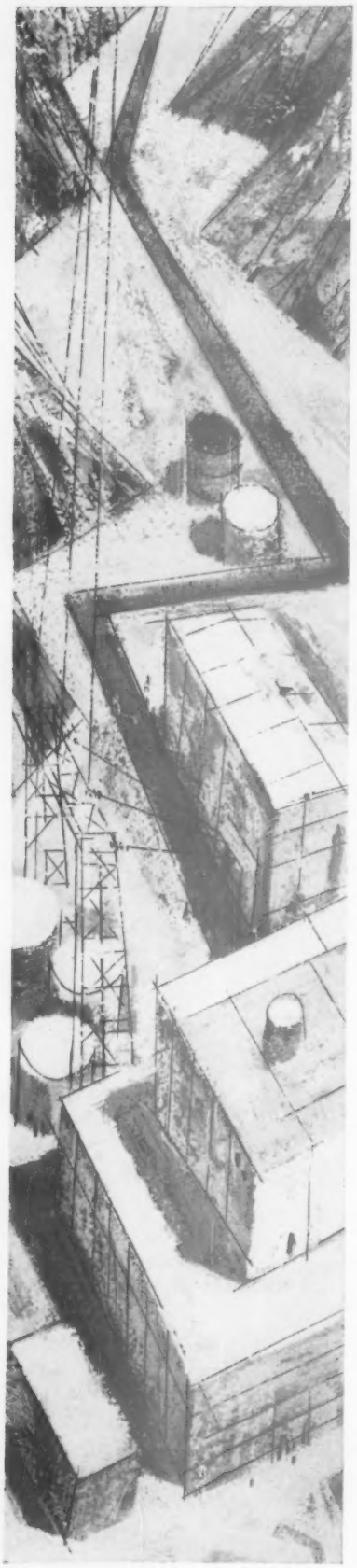

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APPLIED RADIATION

This article starts on page 90

tron, which has lower energy but definitely greater beam currents.

As a standard oxygen source with which our unknown was to be compared we used a chemically analyzed sample of 2,100-ppm oxygen contamination 0.84 cm thick having a density of 1.3 gm/cm³. We anticipate 1.8×10^4 cps after long bombardment times or 5,100 cps after a bombardment time of one minute. Carbon with a 20.5-min half-life and a trio of nuclei (N^{13}, Cu^{63}, and Fe^{54}) having similar half-lives of around 10 min also contribute detectable activities. In actual count the analyzed experimental result was 5,500 cps.

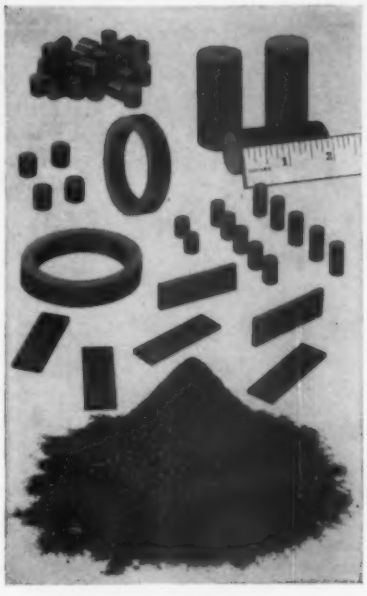
A similar calculation for our carbon standard yielded 970 cps for 23-sec bombardment of polyethylene as against a measured 800 cps. We use these calculations only as a check and for an understanding of the method; for precise analysis counting rates from an unknown sample are compared with standard samples of known contaminant concentration.

Measuring Unknowns

To test our calculations and over-all sensitivity we have prepared polyethylene, pressed-flake beryllium and unanalyzed beryllium samples. The analyzed beryllium, furnished by the Beryllium Corp., had an oxygen content of 0.21%. The unknowns have small but unknown carbon and oxygen contaminations. All samples are ~1 cm thick and large enough in area to intercept the bremsstrahlung beam completely.

After correcting for background (~1% of the counting rate at the beginning of each run) data are plotted to determine the half-life of the measured activities. In Fig. 2 are the data from a 1.3-cm-thick beryllium sample with a density of 1.75 gm/cm³. This plot indicates three activities with half-lives of ~2 min, 20 min, and 10 min. They can be presumed due to O^{15}, C^{11}, and one or more of the trio N^{13}, Cu^{62} and Fe^{53}.

Taking 2.05 min for the half-life of O^{15} (*10*), 20.5 min for the half-life of C^{11} (*11*), and 10 min as a rough value for the small contamination due to the trio, we use three widely spaced data points to obtain three simultaneous equations in the unknown concentrations of these contaminants. We choose three points at times about equal to the three half-lives and sub-



UO_2

...in any enrichment
...as sinterable powder
...as high-fired powder
...as high-fired spheroids
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...pure, or in combination with other materials, such as ThO_2

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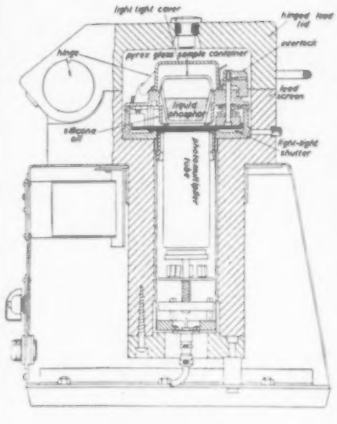

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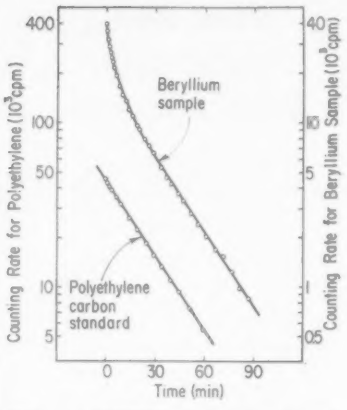


FIG. 2. THEORY FITS experimental points. Choice of constants in 3-term decay equation fits lines to points and determines amounts of contaminants

stitute into the equation

$$D(t) = C_O e^{-\lambda_O t} + C_{Cu} e^{-\lambda_{Cu} t} + C_C e^{-\lambda_C t}$$

to obtain a counting rate D of

$$D(t) = 300e^{-0.330t} + 104e^{-0.0760t} + 260e^{-0.0338t} \text{ cps}$$

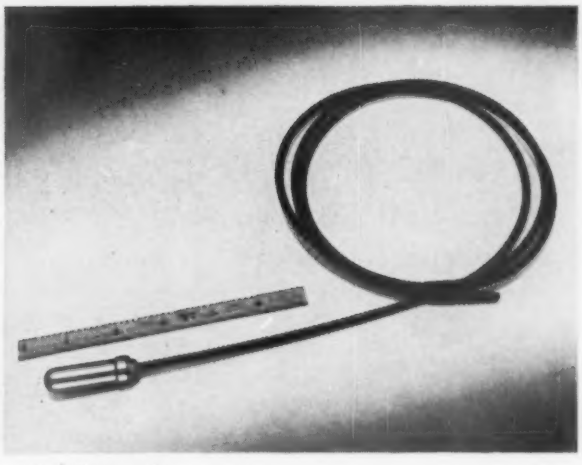
at times measured from one oxygen half-life after the bremsstrahlung beam is turned off. This curve is shown in Fig. 2 and fits the experimental points very well. This corresponds to a counting rate at cessation of irradiation of 615 cps due to O^{15}, 120 cps total due to N^{12}, Cu^{62} and Fe^{53}, and 280 cps due to C^{11}. This result was for a total bombardment time of 4 min; for infinite bombardment times we calculate the corresponding counting rates to be: 840 cps for O^{15}, 426 cps total for N^{13}, Cu^{62} and Fe^{53}, and 2,205 cps due to C^{11}.

A standard (2,100 ppm oxygen, density of 1.3 gm/cm³, thickness 0.84 cm) was bombarded for 1 min with a beam 0.153/0.175 as intense as the beam used in bombarding the unknown and gave a similarly analyzed O^{15} counting rate of 5,530 cps, which corresponds to 19,700 cps for infinite bombardment time. The oxygen concentration in the unknown is found by allowing for the differences in bombardment intensity, density, and thickness between the standard and the unknown

$$\frac{840}{19{,}700} \times \frac{1.3}{1.75} \times \frac{0.84}{1.3} \times \frac{0.153}{0.175} \times 2{,}100 = 38 \text{ ppm}$$

Carbon calibration. To calibrate for carbon, we irradiated a poly-

Teletherapy



Radiography

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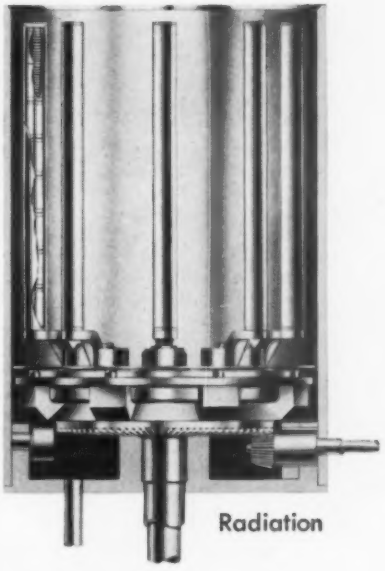

Radiation

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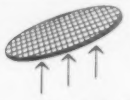
a filter man's thinking

"Expediency: when time is more precious than gold (or platinum)"

BY JULES P. KOVACS, V. P., PUROLATOR PRODUCTS, INC.

There's more than one way to skin a cat . . . or filter a chemical that fights any attempt to tame it.

As an example, here's a problem we recently licked in developing a diffusion plate bed support for a highly corrosive gaseous fluidized bed reactor, operating at very high temperatures. Pore size had to be 25 microns, able to support 20 psi. And it was needed in a *hurry*.



Now, anyone who knows filters could pick metals for such a job. The obviously ideal medium would be inconel. Trouble was, it was impossible to obtain a fine enough inconel screen. Of the only other metals that could withstand the corrosive action, gold lacked high temperature strength; platinum was too weak without support and too costly, though it did offer the high temperature strength and corrosion resistance needed. And that's where Purolator's special capabilities came into play.

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APPLIED RADIATION

This article starts on page 90

ethylene sample 0.305 cm thick of density 0.97 gm/cm³ for 23 sec in a 0.154-μa beam. The initial counting rate was 800 cps, which corresponds to 62,000 cps for infinite bombardment times. A plot of these data is shown in Fig. 2. Owing to geometrical factors the over-all detector efficiency was only about half as great for the very thin polyethylene target as for the thicker targets. The target contained 1.2×10^{21} carbon atoms/cm², and therefore the unknown must have had

$$\frac{1}{2} \times \frac{2{,}205}{62{,}000} \times \frac{1.0}{1.3} \times \frac{0.154}{0.175} \times 1.2 \times 10^{21} = 1.45 \times 10^{19} \text{ carbon atoms/cm}^3$$

In a sample of beryllium with a density of 1.75 this corresponds to $[(1.75/9) \times 6 \times 10^{23} \times 9/12]^{-1} \times 1.45 \times 10^{19} =$ 164 ppm of carbon by weight.

The 10-min activity of 426 cps for the nitrogen-copper-iron trio is in agreement with the expected counting rate estimated from the chemically determined concentrations of 10 ppm of copper and 250 ppm of iron.

Conclusions

The results of the experiment are consistent with the calculations from theoretical considerations and chemical analysis. We feel that even in the presence of this high carbon background satisfactory analysis can be performed on samples having one fifth as much oxygen as the one used here, especially if the bombardment time is reduced. We are continuing work as purer samples become available and anticipate a maximum sensitivity with the present apparatus of about one ppm for both carbon and oxygen when higher-purity beryllium becomes available to us.

* * *

The authors acknowledge their gratitude to Carl F. Barber of Stanford University and the crew of the 40-Mev linear electron accelerator for their assistance in making the experiment possible, to James Rowland of Lockheed for his assistance in taking and analyzing the experimental data, and to Clayton Matthews of the Metallurgy and Ceramics Department, Lockheed Research and Development Branch for his interest in and support of their work.

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Measuring the change of dose rate from the source indicates that the source is not losing its polonium. Nevertheless the system is operated in a hood in case there should be any loss.

* E. J. Hart, J. Terandy, *Rev. Sci. Instr.* **29**, 962 (1958)

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A new target that we use with our 3-Mev Van de Graaff accelerator produces what we believe is the highest neutron-free photon dose rate ever achieved. We can obtain 10^8 r/hr in a volume of 1 cm³ close to the face of the target. The whole secret is adequate cooling for the absorption of the 1-ma beam and optimal geometry.

Need for High Rates

Doses required for studies in radiation chemistry range from 10^4–10^5 rads for long chain reactions such as halogenations to 10^9–10^{10} rads for radiation-damage studies on radiation-resistant materials. Doses for polymerization of monomers, graft copolymerization, and polymer treatment are in the range of 10^6–10^8 rads, and those for radiolysis mechanism studies are in the range of 10^7–10^8 rads.

For the greatest flexibility in these various fields an electron accelerator is useful as a radiation source. However, for applications where the limited penetrating power of the electron beam is a problem, more penetrating electromagnetic radiation is needed. Bremsstrahlung produced by absorption of the electron beam in a heavy metal target can be used. Conversion efficiency is limited; however, it increases with electron energy from 6% at 2 Mev to ~40% at 20 Mev.

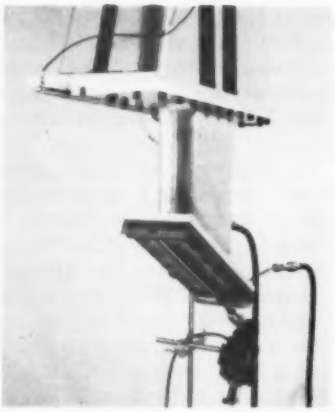

FIG. 1. GOLD TARGET produces up to 10^8 r/hr in rotating titanium sample tube owing to geometry and rapid cooling

Our electron Van de Graaff can give photon power at 300 watts by absorption of the electron beam in a gold target. This is equivalent to the entire gamma power output of 20,000 curies of Co^{60}. However, the accelerator has the advantage that the power is directional; the intensity in the forward direction is equivalent to that from a point source of 100,000 curies of Co^{60}.

Isotopic radiation sources can provide gamma-ray dose rates in the range of 10^5–10^7 rad/hr; maximum value is set by the specific activity of the material. While samples can be exposed to such sources for days or weeks without attention, similar irradiations with accelerator bremsstrahlung sources require an accelerator operator. Relatively short irradiation times are therefore required. Thus, it is important to design the target to provide a higher dose rate. This can be achieved by designing it to be as near a point source as possible, with close access of sample.

Target Design

Our new target design (Figs. 1 and 2) approaches the above ideal. The entire 3,000 watt electron beam, 3 mm in diameter, can be absorbed in the gold without scanning. Heat is quickly removed by a 1-mm sheet of water passing the underside of the 3-mm gold strip. The water channel is provided by a thin sheet of copper soldered to the face of the target block. The beam heats water passed at the rate of 4 liter/min by 10° C. Samples for irradiation can be placed against the face of the target block, only 2 mm from the target. For ease of handling liquid samples, the target block is held at 30° from the horizontal, with a vertical electron beam. Heated or cooled gas passing through the sample tube controls sample temperature.

With a 2-cm scan of the 3-Mev, 1-ma beam, bremsstrahlung provides a dose rate of 1.03×10^8 rad/hr to a 1-cm³ liquid sample in an 8-mm i.d. tube at the optimum position. This can be compared to the dose rates attainable in many Co^{60} and spent-fuel-element installations ranging from 10^5 to 2.5×10^7 rad/hr (*1*). Thus, the dose rate from this target is believed to be the highest that has been applied to a chemical sample in the absence of neutrons; it is actually of the order of the dose rates for mixed radiations in the cores of operating nuclear reactors.

An approximate calculation of the photon flux impinging on the sample yields a value of 1×10^{14} photons/cm²/sec. This is derived from the energy absorption (1.74×10^{18} ev/gm/sec), the energy absorption coefficient in this energy range (0.03 cm²/gm) and an assumption that the average photon energy is 0.6 Mev.

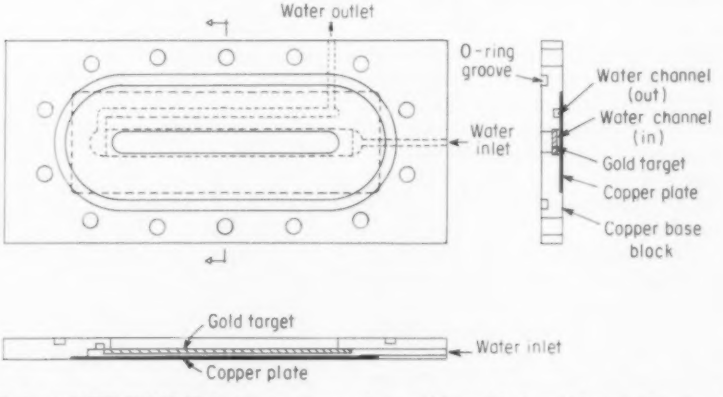

FIG. 2. WATER CHANNEL between copper plate and base block enables rapid removal of electron-beam energy

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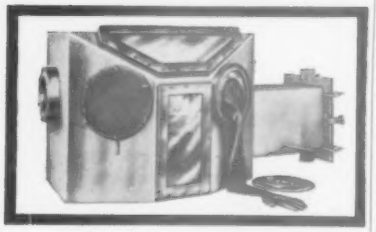

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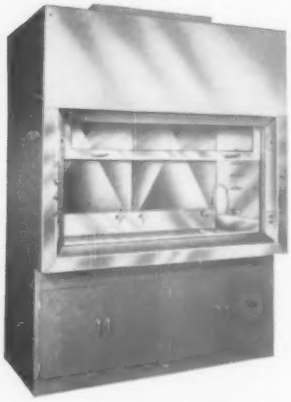

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Zircaloy or Stainless Clad?

This article starts on page 64

U. S., as it does at present for foreign nations. Thus, partial cost $\bar{C}_{12^{\gamma}}$ was calculated at both the \$30 and \$12 base level. The interest on the U inventory is at present fixed by the AEC at 4%. This provides a partial subsidy for atomic reactors. In a free market, the cost of capital would be more like 12% and, therefore, partial cost $\bar{C}_{UN}$ is figured at both 4% and 12%. The investment of money tied up in fabrication costs must also be allowed interest. At present, this cost is not subsidized by the AEC and has been estimated at 12%.

Two cost bases have been selected for the comparison between stainless and Zircaloy cladding. One is the present U. S. cost with Pu at \$30/gm, U inventory at 4% and fabrication cost interest at 12%. The other is a possible future U. S. cost, if all AEC subsidies were eliminated, with Pu at \$12/gm, U inventory at 12% and fabrication cost interest at 12%. This comparison is presented in the illustration.

Conclusion

The comparative fuel costs with stainless and Zircaloy cladding for equivalent burnup are shown in the illustration.

The comparison of the fuel costs obtained with Zircaloy-2 cladding with those for stainless-steel cladding indicate that Zircaloy-2 cladding would give a lower total fuel cost in this reactor at present prices for all burnups above about 12,000 Mwd/tonne. Since the fuel-cost curve shows a long minimum, substantially flat between burnups of 18,000 and 50,000 Mwd/tonne, it would be economically desirable to operate at burnups >18,000 Mwd/tonne. Fuel fabricators at present are unwilling to guarantee elements above 15,000 Mwd/tonne. However, there is considerable experience at burnups up to 30,000 Mwd/tonne, which suggests that the upper limit of burnup can be considerably advanced in the near future.

The comparison of the preceding paragraph was made using present U. S. prices for Pu of \$30/gm and U inventory interest at 4%, as subsidized by the AEC. It is expected that after 1962 the AEC will allow only \$12/gm for Pu and may cease to subsidize the U inventory. Under these conditions, the possible future U. S. costs for fuel would be considerably higher. The comparison between stainless and Zircaloy cladding at these higher costs indicates that Zircaloy cladding is more economical at all burnups above ~4,500 Mwd/tonne.

With present U. S. costs, a reactor of this type operating at a burnup of 15,000 Mwd/tonne, and using Zircaloy cladding, would save \$165,000 per year (about 8%) on fuel costs over one using stainless-steel cladding. With possible future U. S. costs, the amount saved by the use of Zircaloy would be \$600,000 per year (about 11.5%). These figures are net and take account of the higher price of Zircaloy cladding.

Although the absolute values for fuel cost are subject to any errors in the cost assumptions made, the relative economy of stainless or Zircaloy cladding is accurately indicated. It may be concluded that, under present U. S. conditions, lower fuel costs can be obtained with Zircaloy cladding. In the foreseeable future, the advantage of Zircaloy over stainless-steel cladding will probably increase.

• • •

The authors express their appreciation to Prof. T. J. Thompson and Mr. J. P. Cunningham for permission to use nuclear calculations given in Mr. Cunningham's thesis dealing with a reactor with stainless-steel fuel cladding and to Mr. K. R. Goller for permission to use nuclear calculations from his thesis dealing with a reactor with Zircaloy fuel cladding.

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THERMONUCLEONICS

Cyclotron Radiation Still Worrisome Radiation from the circular orbits of electrons in plasma devices is still regarded as potentially a source of considerable power loss from thermonuclear devices. The loss mechanism, first posed in Geneva paper 2213 by B. A. Trubikov and V. S. Kudryatsev of the USSR (NU, Sept. '58, 23), arises because the centripetal acceleration of spiraling electric charges necessarily causes them to radiate in the microwave region. The deuterium ions, possessing a greater mass, move slowly and their emission of electromagnetic energy is insignificant. The electrons, on the other hand, move with relativistic velocities, and the relativistic effects of their motion might result in so serious a power loss as to seriously circumscribe the future of controlled thermonuclear research.

Cyclotron radiation increases very rapidly with temperature, and increases only linearly with the plasma density (in contrast to the quadratic dependence on density of the power generation). Trubnikov and Kudryavtsev predicted, therefore, that in order to attain controlled fusion power, higher plasma densities of much larger dimensions than heretofore contemplated by fusion researchers would be required.

Marshal M. Rosenbluth of General Atomic pointed out at the recent Sherwood theoretical conference at Gatlinburg, however, that Trubnikov and Kudryavtsev neglected to include the great decrease in emission as the angle of emitted radiation with the plane perpendicular to the confining field is increased. The energy loss would be further minimized by reflections of the emitted microwaves from the walls or copper coils surrounding the plasma. The Russians, therefore, overestimated the emission by about two orders of magnitude. Furthermore, as Trubnikov and Kudryavtsev themselves emphasized, only the high-energy electrons in the tail of the Maxwell-Boltzmann distribution lose energy rapidly, and since these electrons do not interact effectively with the rest of the plasma anyway, the only result may be a slightly altered electron velocity distribution in the plasma.

Consequences. If cyclotron radiation should prove serious, all magnetically-contained fusion devices would be affected, some more than others. In Sherwood-type plasmas, electron collisions occur very infrequently compared with the period of their motion in the magnetic field. As a result, motion along magnetic field lines is almost completely separate from motion perpendicular to the confining field. Indeed, the two motions may even have, and in a magnetic mirror geometry must have, different "temperatures." The emission of microwaves unfortunately takes away energy only from the perpendicular motion of the electrons, leaving untouched the energy in the motion parallel to the magnetic field.

Thus in a Stellarator type of geometry, the cyclotron emission would result in motion predominantly along the magnetic field lines for the electrons of highest energy. Devices employing magnetic mirrors like the Pyrotron at Livermore are particularly vulnerable because of this effect since containment is reduced if the electrons move at smaller angles to the magnetic field. Thus high-energy electrons would be quickly lost through the mirrors. If this occurred for an appreciable fraction of electrons, the escaping electrons would pull the positive hydrogen ions after them.

In a pinch device the radiation loss would occur both along and perpendicular to the axis of the pinch due to the presence of an axial stabilizing field. The pinch, therefore, will probably lose power at a higher rate than the Stellarator or the Pyrotron, particularly if it must run at the higher temperatures presently envisaged for some pinch devices. Other very promising devices using magnetic-mirror geometries, such as the Astron at Livermore or the DCX at Oak Ridge, are especially prejudiced by the possibility of cyclotron emission because they operate at exceptionally high electron temperatures.

These significant potential consequences cause cyclotron radiation to be the subject of continuing concern on the part of fusion researchers. Further theoretical and experimental work will be required to determine just how real the threat is.

* * *

This account is based on material provided by David B. Beard, Univ. of California, Davis, Calif.

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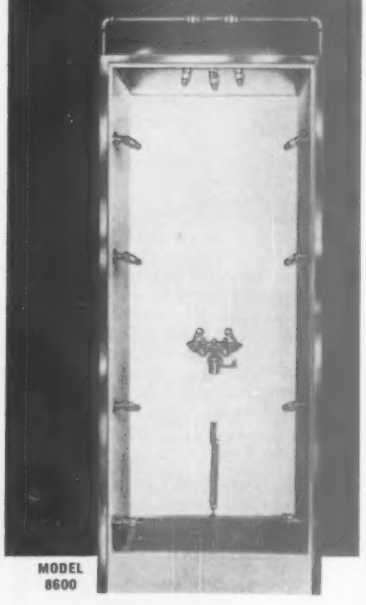

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RUSSIAN NUCLEONICS

Burnout Heat Flux Versus Pressure

A Russian experimental heat-transfer loop has yielded data on the burnout heat flux for pressurized water over a region where even the water-conscious U. S. program previously had had only meager information. I. T. Aladev et al. [I. T. Aladev, L. D. Dodonov, V. S. Udalov. "Burnout Fluxes for Water Flowing in Tubes," *Atomnaya Energiya* **6**, No. 1, 74 (1959)] summarize the measurements of the burnout heat flux of water in round tubes for various flow rates and subcooling temperatures over a range of water pressures from 300 to 3,000 psi. The tubes tested in the experimental loop were of chrome-nickel steel with a 0.4-mm. wall and an internal diameter of 8.2 mm; an electric current passed through the length of tube simulated the nuclear heat flux. The work was done during the year 1956–57 at the Power Institute of the Academy of Sciences.

The greatest part of the U. S. burnout measurements have been made in the vicinity of 2,000 psi. A recent Bettis report deplored the lack of data on the variation of burnout flux with pressure in the region from atmospheric pressure up to 2,000 psi. This information would be useful in making core-safety calculations and fixing the optimum pressure for operation.

The Russians find that the burnout flux decreases by a factor of 4–5 as the pressure increases from 600 to 3,000 psi; between 300 and 600 psi the burnout flux remains constant. Previous U. S. data [W. H. Jens, *Mech. Eng.* **76**, No. 12, 981 (1954)] over a narrower range had suggested the former variation but not the latter. The Russians also find an unexplained factor-of-two difference in absolute value between the U. S. and USSR values.

* * *

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(IN THE NOVEMBER ISSUE)

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BOOKS

Nuclear Engineering Handbook

HAROLD ETHERINGTON, editor (McGraw-Hill Book Co., New York, 1958, 1,857 pages, $25.00)

Reviewed by G. GOERTZEL and R. C. Ross, Nuclear Development Corp. of America, White Plains, N. Y.

There has been a need for some time in the nuclear engineering field for a compilation such as this handbook. The information is generally authoritative and up to date, and much of it is hard to find conveniently elsewhere. It will therefore be useful in the library of any group engaged in nuclear activities.

The book, prepared by an impressively qualified group of authors, is divided into 14 chapters:

Mathematical Data and General Tables; Nuclear Data; Mathematics; Nuclear Physics; Experimental Techniques; Reactor Physics; Radiation and Radiological Protection; Control of Reactors; Fluid and Heat Flow; Reactor Materials; Chemistry and Chemical Engineering; Nuclear Power Plant Selection; Mechanical Design and Operation of Reactors; and Isotopes. The 70 contributors include such prominent names in the nuclear field as Etherington (also the editor), Aebersold, Blizard, Bonilla, Householder, Huffman, Hughes, Leverett, McCullough, Siegel, Soodak and Zinn.

This is a first attempt at putting such a monumental work together. As might be expected, along with the positive features of the volume, there are some defects that should be corrected in subsequent editions if the handbook is to be the complete, single-volume compilation it is intended to be.

Some specific comments we have are:

The engineering sections (essentially the last half of the book) are useful, particularly the coverage given to specific reactors and reactor systems. The theoretical sections develop much of the required theory although they give little in the way of results.

Steam cycles are well treated. Much more could be usefully said, however, on gas cycles and other working fluids.

The chapter on materials is generally valuable, although proportionately little attention is given to the vital subject of radiation damage to fuels.

The mathematical sections leave something to be desired: the chapter on mathematics consists of tutorial sections on "Algebra and Geometry" and "Analysis" and a very brief and descriptive one on automatic computers, instead of the customary and useful concise tabulations of formulas; also the tables in section 1-2 are not as extensive nor as conveniently presented as in some other standard handbooks.

The usefulness of section 1-1, "Selected Data and Formulas and Guide to the Handbook," consisting mainly of a partial abstract of the rest of the book, is not obvious.

This, then, is an important addition to the nuclear engineering literature. Given certain improvements in subsequent editions, it can eventually join such classics as Marks's "Mechanical Engineering Handbook" on technical bookshelves.

Radioisotopes in Scientific Research, Vol. 2, Chemistry and Geology

R. C. EXTERMANN, editor (Pergamon Press, New York, 1958, 741 pages, $22.50)

Reviewed by V. P. GUINN, Shell Development Co., Emeryville, Calif.

This excellent volume includes the complete text of the 53 papers concerned with research with radioisotopes in chemistry and geology that were presented at the UNESCO International Conference on Radioisotopes in Scientific Research, held in Paris, September 9–20, 1957. Each paper also includes abstracts in four languages (English, French, Spanish and Russian) and a record of the discussion following the paper.

The papers are presented in either English (41) or French (12). The contributions are from twelve countries: U. S. S. R. (13), U. S. A. (10), U. K. (8), France (6), Belgium (5), Japan (3), Spain (2), Germany (2), Italy (1), Canada (1), Czechoslovakia (1) and Brazil (1). Many well known workers in the field are represented, e.g., Roginsky, Collins, Balandin, Rowland, Wolfgang, Wolf, Libby, Leveque, Peirson, Iredale, Irvine, Rona, Dainton, Coryell, Curran and Kohman. In the various papers a total of 713 literature references are cited.

The papers are listed in three main categories: chemistry (39), geophysics (12) and radioisotope production (2). The chemistry papers are further subdivided into four groups: organic chemistry (8), recoil chemistry (6), analytical chemistry (8) and physical chemistry (17).

The book suffers from the basic difficulty of any collection of papers given at a meeting: the styles are quite varied and the quality spotty, since the papers are in the words of the original authors. In spite of this drawback, however, the volume is to be recommended on the basis of the relatively high percentage of high-caliber, fairly up-to-date papers included.

The papers on recoil chemistry are especially good. They include papers on recoiling tritium atoms, by Rowland and Wolfgang; on recoiling C^{14} by, Wolf and by Mackay and Libby; on accelerated C^{14} ions, by the Italian group of Aliprandi et al.; and Szilard-Chalmers reactions in metal phthalocyanines, by Payne et al., of Harwell.

A number of excellent papers on reaction mechanisms are included in the organic chemistry papers, e.g., on the mechanism of the Michael reaction, the Hofmann degradation, the tautomerization of benzylidene benzylamine, heterogeneous catalysis, sulfur isotope exchange, the deamination of amino alcohols, hydrocarbon oxidation and butane-butene-butadiene consecutive reactions.

The analytical papers include papers on neutron activation, the determination of carbon by proton bombardment (to form 10-min N^{13}), analytical gamma-ray spectrometry, chromatographic separation of the alkali and alkaline earth metals, the evaporation of elements in arc and spark sources and the development of new analytical methods.

The physical chemistry papers include papers on exchange reactions, diffusion, self-diffusion, vapor pressures, surface reactions, dosimetry, heteropoly compounds, chelation, electromigration in fused salts, solvent extraction and adsorption.

A number of outstanding geophysical papers are included, for example, those on movement of cosmic-ray-produced and bomb-produced tritium by Begeman and Libby; on cosmic-ray-produced Al^{26}, Be^{10} and Co^{60} in meteorites and tektites by Kohman and Ehmann; on the in situ tracing of tagged sand and pebbles, underwater, by Smith and Eakins; on low-background counters with zero wall contamination by Moljk, Drever and Curran; and on the analysis of antique relics by beta-particle back-

scattering by the Japanese group of Asahina, Yamasaki and Yamasaki. Good papers are also included on K^{38} in nature, A^{40}-K^{40} age dating, natural radioactivity of Lu^{176}, sulfur isotopic composition in meteorites, U^{238}, Th^{230}, Th^{232} and Ra^{226} in deep-sea sediments, and cosmic-ray-produced Na^{22}.

The French paper on radioisotope production deals with the separation of Cs^{137} from mixed fission products. The British paper describes the separation of kilocurie amounts of pure Cs^{137} from mixed fission products and also the isolation of Np^{237} and Tc^{99}.

Geneva '58 Proceedings

The massive proceedings of the "Second United Nations International Conference on the Peaceful Uses of Atomic Energy" are now appearing, volume by volume, with commendable dispatch. The project doubles in size that of the 1955 conference—2,135 papers in 33 volumes, compared with 1,067 '55 Geneva papers in 16 volumes. With the complete set, one will have the entire world nuclear effort, if not in a nutshell, at least on a book shelf. All the volumes are expected to be available in late summer.

The following descriptions cover volumes thus far available to us.

Vol. 2, Survey of Raw Material Resources (843 pages, $18.50), contains the 102 papers of the sessions on Raw Material Supplies; Geochemistry; and Mineralogy, Geology and Prospecting. Greater willingness on the part of some countries to release data on uranium and thorium reserves, as well as more accurate data, establishes a resources picture that is much more optimistic than that forecast at the 1955 meeting. Great advances have been made in geology and geochemical and other prospecting techniques.

Vol. 3, Processing of Raw Materials (607 pages, $15.00), in addition to vol. 2, illustrates the present emphasis on raw-materials technology, including improved yield from ores, as opposed to unlimited exploration for new ore beds. Developments in prospecting instrumentation show improved design rather than radical changes. Advances are also reported in ore processing, e.g., solvent extraction and ion-exchange resins; processing occupies the bulk of the volume.

Vol. 4, Production of Nuclear Materials and Isotopes (631 pages, $16.50), contains papers of the sessions on Production of Nuclear Materials and Methods of Separating Isotopes. Uranium production is covered from purification of the concentrates through UF_6 reduction. Other papers discuss the production of thorium, graphite, zirconium, beryllium, vanadium, niobium, hafnium, tellurium and the rare earths. In the isotope separation field are papers on theory and gaseous-diffusion and electromagnetic separation. Heavy-water, boron and light-element separations are described.

Vol. 23, Experience in Radiological Protection (453 pages, $14.50), covers the philosophy, instrumentation and handling of the radiological protection of personnel. The discussion is based on research results as well as actual incidents. Hazards relative to industrial use, reactor facilities, isotope sources and radiation machines are considered.

Vol. 30, Fundamental Physics (329 pages, $10.50), contains the papers of session 15 (Recent Developments in Fundamental Physics) and session A-17 (Physics of Elementary Particles and High Energy Machines). Of particular interest in the eight papers of the first session are those by Chew (Pions and Antinucleons), Feynman and Gell-Mann (Theoretical Analysis of Strange Particles), and Wu and Lederman (Weak Interactions). The second has 45 papers, most of which are in the areas of cosmic rays, accelerator and bubble-chamber design, mesons and strange particles, and weak interactions.

Vol. 31, Theoretical and Experimental Aspects of Controlled Nuclear Fusion (390 pages, $15.00), contains the papers of session 4: Possibility of Controlled Fusion; session A-5: Theoretical Aspects of Plasma Physics; and session A-6: Experimental Aspects of Plasma Physics. The five papers of session 4 review the status of controlled fusion in Sweden, the U. S. S. R., the U. S., West Germany and the U. K. The papers of the theoretical session (33 in all) report in patchwork form on the world's understanding of the various pieces of the controlled-fusion problem. The experimental session (14 papers) mostly discusses fundamental studies and techniques (such as shock heating, high-current discharges and new injection methods) without reference to specific devices, which are discussed in a forthcoming volume. Exceptions are papers describing the DCX, the Ixion and Luce's carbon arc.

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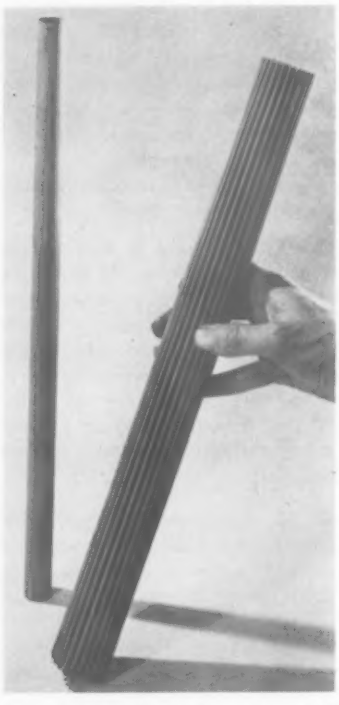

Filters for Nuclear Service

Purolator Products, Inc., has been in filtration of all kinds and types since 1923 and can supply the complete filter package, not just various filter media, but the housings, connections, frames, valves, assemblies, etc. The company can handle pressure vessels weighing up to 5 tons; can weld, form, machine, etc. Purolator manufactured dummy inner and outer radial blanket assemblies for Atomic Power Development Associates (APDA), who will use them in the test runs of the Enrico Fermi reactor. The 500 plus units are approximately 96 in. long and $2\frac{1}{2}$ in. square at the center, developing to smaller diameters at the ends. During the production of these fuel elements, the company developed, in conjunction with APDA, a new technique for surgically cleaning the fuel pins.

For a pressurized-water-reactor installation, Purolator engineers used a metal-edge medium in a filter element that measured $5\frac{1}{2} \times 18$ in. and contained more than 156,000 openings no larger than 50 μ. Coolant flow through the filter is 2,000 gpm with pressure drops of 3–4 psi. Metal-edge filters (such as that shown above, left) are made by spiraling a trapezoidal-shaped ribbon of wire into a cylindrical form. Every inch of wire in the cylinder contains from 7 to 20 tapered risers formed into the metal ribbon by high-alloy roller dies. Each riser, after being shaped into cylindrical form, is integrally resistance-welded by a process that makes upwards of 15,000–20,000 welds/min.

Porous-metal media (as above, right), formed from metallic powders and fibers, have been designed especially for filtration of exotic gases under extreme temperatures and highly corrosive atmospheres. For example, a porous metal filter, constructed entirely of Monel, is used in a uranium hexafluoride plant to filter desiccant from fluoride gas streams. Practically all known metals and alloys are used in these filters, porous metal media can be constructed from most stainless steels and nickel, vitallium, platinum, Hastelloy, gold, silver or tantalum.

Latest development is a diffuser filter or plate which consists of two sections of metal-edged disks placed 90 deg from one another along their unidirectional strength axis to provide bi-directional strength. Both parts are then used together in special ring supports by a powdered-metallurgical process. This filter assembly is used in fluidized-bed-reactor systems to support the bed and diffuse the fluidizing gas stream simultaneously, thus providing uniform distribution of the gas. The diffuser filter operates at 1,000° F, 30 cfm and 15 psi and is ~3 in. in diameter.—Purolator Products, Inc., Rahway, N. J.

Gamma Dose-Rate Meter

Model 592B is contained in light, weathertight case of Fiberglass-reinforced resin and has only two controls, a range switch and a zeroing knob. All high-impedance circuitry is hermetically sealed and range switching is performed in low-impedance portion of circuit. Sensitivity ranges are: 0–10, 0–100 and 0–1,000 mr/hr. Feedback circuit gives rapid response of 90% of final indication in <1 sec, even in 0–10 mr/hr range. Instrument accuracy is conservatively rated at $\pm 10\%$ of true dose over the energy range from 50 kev to 1.3 Mev.—The Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

Photomultiplier

Model BMS 10/14 is miniature high-sensitivity 10-stage photomultiplier $\frac{3}{4}$ in. in diameter and <4 in. in length. Multiplier is fitted with special 12-pin molded glass base for which molded sockets are available. When coupled to $\frac{1}{2}$-in.-diameter NaI crystal, resolution of the order of 10% is obtained with Cs^{137}. When operated with interdynode voltage of 100 v, tubes have minimum over-all sensitivity of 150 amp/lumen.—20th Century Electronics, Ltd., King Henry's Dr., New Addington, Croydon, Surrey, England.

Fuel-Element Fabrication

Custom-made ceramic fuel pellets, fuel-element assemblies, detector foils and magnesium oxide parts for thermal insulation are available. Compounded of urania or urania-thoria mixtures, fuel pellets ranging from $\frac{1}{8}$-in. to 1-in. in diameter can be produced. Right cylinders, tubes, plates and other shapes can be fabricated in reactor-loading quantities. Facilities and materials are also available for "canning" pellets in stainless steel, zirconium, aluminum, coated graphite and other materials as well as assembling cans into complete fuel elements. Thermal-neutron detector foils of dysprosium, (Dy_2O_3) gadolinium (Gd_2O_3) or other rare earth oxides dispersed in aluminum oxide can also be furnished on custom-made basis.—American Lava Corp., Chattanooga, Tenn.

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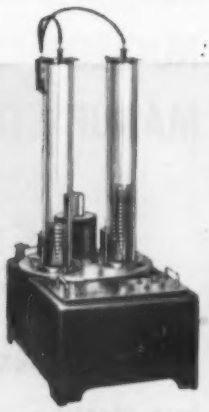
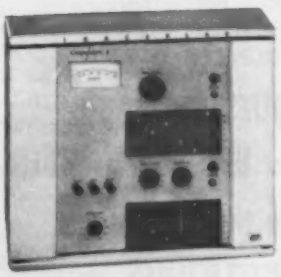
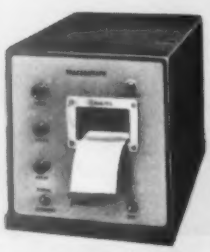


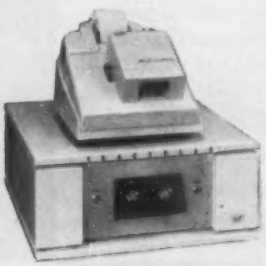
SC-30B AUTOMATIC
FLOW COUNTER

Tracerlab Automatic Sample Changers can be used interchangeably with Tracerlab Scalers such as the Compu/matic model shown at the right and with data printout equipment such as that shown below to constitute a truly automated sample counting system.

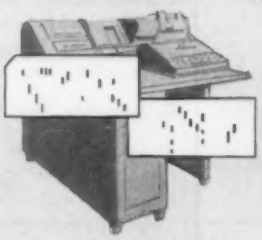




SC-5F TRACERGRAPH
prints out time and sample number on a standard adding machine tape.



SC-88 *Auto/computer*
prints out time, sample number, total count and counts per minute on a standard adding machine tape.



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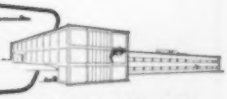

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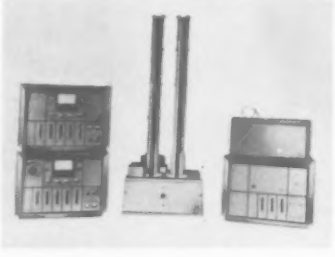
PRODUCTS & MATERIALS

Department starts on page 106

mounts by means of two beveled welding nipples of 1-in. schedule-80 steel pipe. Body of control is formed from two sections of 5-in. schedule-80, seamless, alloy-steel pipe (ASA 335 Grade P-11). Float of 3-in. diameter is of heavy-gauge type-316 stainless steel Heliarc welded to counter-weighted float stem. Switch mechanism will operate with liquid temperatures of 1,000° F and with liquids of 0.65 specific gravity (at operating temperature) and up.—Magnetrol, Inc., 2110 S. Marshall Blvd., Chicago 23, Ill.



Sample Changer

Model SC automatic sample changer (above) has new type loading and unloading mechanism with capacities of up to 1,000 planchets having diameters of 5 in. or greater. Other features that can be provided are two or more detector heads permitting separate measurements of alpha, beta, and gamma radiation from sample and direct print-out of sample number and count to preset time, or sample number and time to a preset count for each type of radiation. —Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

Ratemeter and Lab Monitor

Model SU-3D basic ratemeter and laboratory monitor is a-c operated count ratemeter with attached thin-window Geiger detector. A loudspeaker provides audible indication of amount of activity being counted. Rear-chassis switch allows panel meter to indicate voltage. Presentation is in cpm with range up to 20,000. Calibration is checked by front-panel control that feeds 7,200-cpm signal into ratemeter circuit. Either of two time constants (1 or 11 sec) can be used.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Read-out Accessory

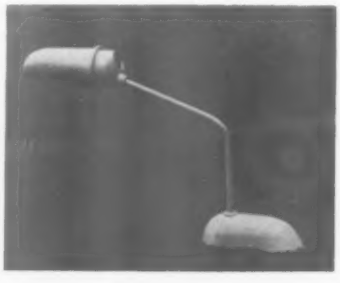
Temperature read-out accessory for recording column or sample-inlet temperatures directly on gas chromatograph charts is designed for installation on 1-mv recorders. Unit consists of switch box and two iron-constantan thermocouples, one for use as reference and the other for sample compartment-temperature readout.—Beckman Instruments, Inc., 2500 Fullerton Rd., Fullerton, Calif.

Tritium Survey Meter

Model TSM-91 portable tritium survey meter and alarm continuously monitors atmospheric and surface radioactive contamination from tritium, carbon-14 and low-energy beta emitters. Survey meter detects air-borne radioactivity by continuous air-intake system that features "flow-through" ionization chamber. It also monitors low-energy betas, in solid or liquid form, with "sniffer" hose attachment. The front-panel meter has 4 ranges and can be read directly in microcuries of tritium per cubic meter of air.—Atomic Accessories Inc., 244-02 Jamaica Avenue, Bellerose 26, N. Y.

Filament Scintillators

Filament scintillators are cut to uniform lengths. In this form, optical light-pipe properties of these filaments are most pronounced. Filament scintillators are available in diameters ranging from 0.5 mm to 1.5 mm and in lengths from 1 to 12 in.—Pilot Chemicals, Inc., 36 Pleasant St., Watertown 72, Mass.



Field-Monitoring System

Weatherproof detector units (above) feed into central multipoint recorder. Each field unit can be located up to 6,500 ft from central station. Detector unit consists of aluminum casting that forms protective cowl for Geiger tube and is so shaped that known ground area is monitored. Casting also houses transistorized amplifier, local ratemeter and a 2½-in. moving coil instrument giving visible indication of local count rate.—Elliott Brothers, Ltd., Lewisham, London SE 13, England.

Hand and Clothing Monitor

Model 42 contamination monitor (above) detects and measures radioactivity on hands and clothing. Measuring time is 6 sec during which 4 meter indicators, 2 for each hand, show activity measured. Clothing contamination is measured by probes located on sides of monitor. One probe contains scintillation detector for α particles, other contains Geiger tube for β and γ rays. Detectors automatically go into operation as soon as probes are unhooked. Probes can be used simultaneously by two persons while a third person is using hand contamination detector. Electronic apparatus is composed of plug-in units, cooling is by closed-cycle ventilation to avoid radioactive contamination from dust setting on inner parts. Feed voltage is 200 v a-c, single-phase, power absorbed is 500 w.—Laboratori Elettronici e Nucleari, SRL, Milan, Italy.

High-Temperature Alloys

A series of columbium-base alloys are characterized by high temperature strength. Fansteel 80 is columbium-zirconium alloy, with melting-point of 4,350° F and density of 8.6 gm/cm³. Fansteel 82 is columbium-tantalum-zirconium alloy with melting point of 4,550° F and density of 10.26 gm/cm³.—Fansteel Metallurgical Corp., North Chicago, Ill.

Megatrometer

Model 710 is for measurement of resistance values to 5,000 million megohms. Accuracy in upper half scale is ±3.0%. Unit is portable and incorporates its own transistorized power supply for test potentials to 1,000 v d-c continuously variable. Mercury cells provide

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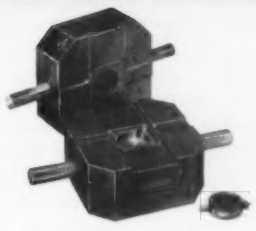
229 Ratemeter

Portable Survey Meter



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BF_3 Neutron Counter

309 Gamma Counter

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For truly precise counting requirements Anton manufactures more than 100 varieties of neutron detectors, halogen quenched counter and integrator tubes, organic quenched, and other types of alpha, beta and gamma detectors. If your specific application is not covered by our tube catalog, we can develop detectors and systems to fill your need. (Request Bulletin 59-T.)

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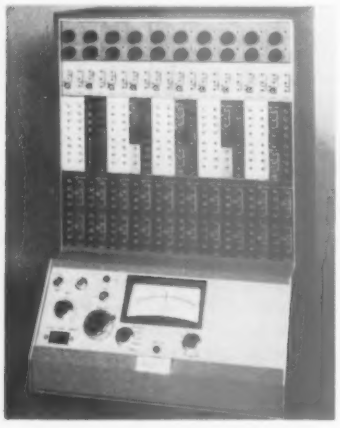
voltage stability with <0.0005% change per hour at 1,000 v. Repeatability is better than 0.2% using certified standard resistors.—Mideastern Electronics, Inc., 32 Commerce St., Springfield, N. J.

Scaling System

Model 0600 system comprises 27 separate decimal scaler channels, each having double pulse resolution of better than 1 μsec. Total storage of 10^6 counts per channel is accomplished with two electronic decades in four-digit mechanical register. Front-panel switches allow cascading of electronic decades to permit handling of higher continuous counting rates where required—Eldorado Electronics, 2821 Tenth St., Berkeley 10, Calif.

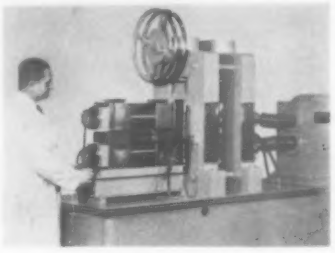


Analog Computer

PACE TR-10 (above) is completely transistorized analog computer 15 in. wide, 17 in. deep, 24 in. high that weighs 80 lb without accessories. It occupies little more desk top area than standard electric typewriter. Compact size plus reliability and accuracy (0.1%) is made possible by design and development of transistorized d-c amplifier, two of which, packaged as single shielded unit, measure only 1½ in. × 5 in. × 6½ in.—Electronic Associates, Inc., Long Branch, N. J.

Vibrating-Reed Electrometer

Model 32 vibrating-reed electrometer is capable of measuring C^{14}-activity to 5×10^{-15} curies per mg Ba CO_3, H^3-activity as low as 10^{-10} curies per mg H^3, and electrical properties as small as 10^{-17} amp and 0.02 mv. Input terminal of Model 32 accommodates ionization chambers of 50–1,500-ml capacity as well as solid and liquid sample accessories.—Applied Physics Corp., 2724 S. Peck Rd., Monrovia, Calif.



Combination Rolling Mill

Heavy-duty, high-precision 2-high/4-high combination rolling mill (above) features complete enclosure in glovebox to allow processing of alpha-active, pyrophoric materials. To facilitate operation in glovebox, mill is equipped with semiautomatic roll-changing device.—Loma Machine Manufacturing Co., Inc., 114 E. 32nd St., New York 16, N. Y.

Film-Badge Service

Film badge service offers following features: Oak Ridge system of neutron threshold foil detector can be incorporated in badge in addition to film packets without measurement interference; cumulative quarterly and annual data reports; microfilming of annual data reports; combination security photo and film badge in single holder for neutron, beta, gamma and X-ray film packets; inherent sensitivity <10 mr for hard X-ray or gamma radiation for total period worn up to several months and <5 mr for soft X-ray or gamma radiation.—Controls for Radiation, Inc., 130 Alewife Brook Pwy., Cambridge 40, Mass.

Miniature Recorder

Rustrak strip chart recorder (above) is available for 0–150 v or 0–300 v a-c (rectifier type movement). Recorder supplements models for d-c currents from 1 ma to 5 amp and voltages to 500 v. Units feature inkless rectilinear recording on 63-ft roll of pressure-sensitive paper. Chart speeds are up to 30 in./hr.—Rust Industrial Co., 130 Silver St., Manchester, N. H.

Film-Badge Service

Film-badge service features continuous cumulative dosage reports for each subscriber plus 24-hr exposure reports on request. Special dosimeter film registers radiation ranges from softest scattered and beta radiation to high-energy gamma and X-ray (25 mr to 300,000 mr) over wide spectrum of energy levels. One-piece, plastic, clip-on badge holds six tamper-proof filters and two lead shields. Fresh film is mailed to clients each monitoring period.—Atomic Film Badge Corp., 244-02 Jamaica Ave., Bellerose 26, N. Y.

Ultrasonic Cleaning Tank

TH series Sonogen ultrasonic cleaning tank/transducers (above) are available with integral heater, dual thermostatic control and twin-wall construction. Ranging from 1- to 32-gal tank capacity, transducer input is from 65 to 1,000 watts.—Branson Ultrasonic Corp., 40 Brown House Rd., Stamford, Conn.

Automatic Spectrometer

Model 50-1 automatic spectrometer consists of Model 33-1 single-channel pulse-height analyzer (modified ORNL Q-1192) containing Argonne, type A61, nonoverloading linear amplifier; Model 39-2 electronic sweep-count ratemeter and high voltage supply and Brown recorder. Electronic sweep circuit is used to automatically scan spectrum between any two predetermined levels from 0 to 85; it then resets and repeats cycle. Data is automatically

plotted on recorder. Automatic sample changer (accessory Model 48-1) can be used to change sample when sweep circuit resets. System can also be operated manually.—Radiation Instrument Development Laboratory, Inc., 5737 S. Halsted St., Chicago 21, Ill.

Voltage-Regulator Tube

Line of subminiature metal-ceramic corona-discharge voltage-regulator tubes covers wide range (400–4,000 v). Regulation is $<1\%$ over current range of 10^{-11}–10^{-7} amp. Prebreakdown current is $<10^{-12}$ amp at room temperature. Tubes operate over range of −55–200° C.—Radiation Research Corp., 1114 First Ave., New York 21, N. Y.

Transistorized Scaler

Model 49-22 offers both preset time and preset count. Digital readout system used is fully transistorized. Resolving time is 0.5 μsec with maximum counting rate of 2 Mc. Count capacity is 10^7, time capacity, 1,000 min. Amplifier sensitivity is 0.5 mv and gain is 1,000. Printed circuitry and modular construction are used throughout.—Radiation Instrument Development Laboratory, Inc., 5737 S. Halsted St., Chicago 21, Ill.

C^{14}, H^3 Counting System

Carbon-14 and tritium liquid-scintillation counting system is accurate with or without a freezer. System includes light-tight sample holder that permits dark preadaptation, sample precooling and use of wide variety of sample shapes and materials. Also included in system are advanced optical system that features coated optics and double shutter system that eliminates all ambient light. "Metalvial" container is designed for optimum photon conservation, minimum fluorescence and maximum blue transmission. Triple shielding keeps background interference to minimum.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

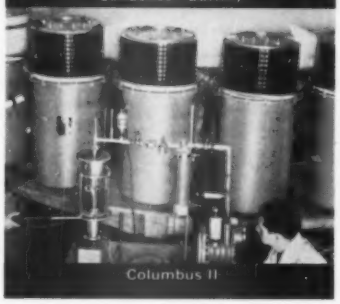
Liquid-Monitoring System

Liquid-monitoring system consists of liquid sampler, scintillation detector (inserted directly into liquid stream), ratemeter, recorder and accessories for particular applications. System can measure alpha, beta or gamma radiation. Detector is housed in its sampler and is secured by leak-proof shock-resisting collar. For alpha monitor, scintillation detector is integral part of sampler. All surfaces in contact with

LOOK TO TOBE FOR PROGRESS

Scylla

Naval Research Lab's Condenser Battery


Columbus II

Tobe... first with condensers for thermonucleonics

Of particular interest to the thousands of international visitors to the historic Geneva Atoms-For-Peace Conference, was the display of thermonuclear fusion research equipment which the U. S. Government set up. Significantly, several of these devices use low-inductance condensers made by Tobe. Three of the machines are shown here.

Even now—long after the conference—Tobe receives inquiries and *orders* from every corner of the globe. The postmarks read like a roll call at the United Nations: Great Britain, Japan, Italy, U. S. S. R., France, Brazil, The Netherlands, Sweden and many others.

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Here are the instrumentation techniques to help you detect, measure, record, and control industrial processes. From simple measuring instruments to complex mathematical techniques, you will find here the kind of help that is valuable, time-saving, and based on the best experience in the field. Covers measurement standards and systems, indicators and recorders, automatic controllers, timers and program controllers, and much more. **Edited by Douglas M. Considine, Manager, Sales Plans, Hughes Aircraft Co. 1383 pp., 1137 illus., $19.50**

ENGINEERING MATERIALS HANDBOOK

This practical volume gives answers to both routine and specialized questions regarding the choice of engineering materials. Considers materials from the viewpoint of engineering structures, machinery and equipment, and includes technical tables, design information, structural characteristics, etc. Emphasis is placed on the fabricated forms of materials, their properties, adaptations, advantages, limitations, competition with each other, etc. **Edited by Charles L. Mantell, Consulting Engineer; Newark College of Engrg. 1952 pp., 678 illus., $21.50**

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PRODUCTS & MATERIALS

Department starts on page 106

liquid are of stainless steel. Alarms are available to warn or actuate other devices.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Pump Impellers

"Bescast" pump impellers (above) are manufactured to customer specifications and range in size from few ounces to 50 lb. Basic types are: shrouded, bucket, fan, mixed flow, and high-speed air impellers. All are precision cast in aluminum.—Brown Engineering Service Co., 29675 Lakeland Blvd., Wickliffe, Ohio.

Scaler

Model SC-700 is decimal scaler with <1 μsec resolution. Instrument features seven decades of decimal count storage, stable feed-back input amplifier with 25 mv sensitivity, integral discriminator and built-in line-frequency test circuit. Provision is made for control of count-start and count-stop by a preset timer. Building block design features plug-in circuit packages.—Eldorado Electronics, 2821 Tenth St., Berkeley 10, Calif.

Isotope Kit

Model SL-71 source kit consists of microcurie amounts of 14 long-lived isotopes, prepared in 5-ml liquid solution and enclosed in ½ oz glass containers. No AEC license is required to purchase either entire kit or individual isotopes.—Atomic Accessories, Inc., 244-02 Jamaica Ave., Bellerose 26, N. Y.

Glass-Fiber Paper

Glass-fiber paper is tested to filter at least 99.98% of test aerosol of 0.25-micron diameter. For dust and aerosol sampling, glass-fiber paper is supplied in 1-, 2-, 3- and 4-in. circles. It is also available in sheets of various sizes.—Gelman Instrument Co., 233 Jefferson, Chelsea, Mich.

H-V Power Supply

Model PS15-5M60S high-voltage power supply has output of 15 kv d-c at 5.0 ma. Ripple is less than 1% at full rated output. Only $4^{9}/_{16} \times 3^{3}/_{4} \times 9$ in., unit is hermetically sealed in oil-filled housing and is operable in temperatures up to 85° C. Either silicon or selenium rectifiers can be used in assembly. Circuit configuration ranges from half-wave to full-wave doubler and full-wave tripler.—Condenser Products, 140 Hamilton St., New Haven, Conn.

Gas-Flow Counting System

Complete gas-flow counting system features flow counter that permits shielded window and windowless counting by interchanging detector chambers. Model FC-72 (Mylar-window counter) differs from Model FC-73 (windowless, preflush type) solely in detector chamber. Counters operate in Geiger or proportional region, and can be used for detecting alpha particles and weak betas such as C^{14}, S^{35}, C^{45} and H^{3}. Complete system includes counters, planchets, gas and gas regulator.—Atomic Accessories, Inc., 244-02 Jamaica Ave., Bellerose 26, N. Y.

Ultrasonic Cleaning System

Series C cabinets provide complete ultrasonic cleaning systems in matched counter-height cabinets (above). Welded of 16-gage type-316L stainless steel to uniform dimensions (26 × 24 × 32 in.) they house Sonogen generator, cleaning tank, filter, rinse tank or dryer. Output of ultrasonic generator at 40 kc is 500 watts (avg) and 2,000 watts peak on pulses. Power input is 1.5 kw. Generator is forced air-cooled, has circuit breaker with indicating light and line-voltage control with meter.—Branson Ultrasonic Corp., 40 Brown House Rd., Stamford, Conn.

LITERATURE AVAILABLE

Subject	*Length*	*Ask for*	*From*
Mixing techniques with radioisotopes	4 pp.	Technical Bulletin No. 2	Nuclear-Chicago Corp., 223 W. Erie St., Chicago 10, Ill.
Shielding oil	—	Bulletin 101	L. Sonneborn Sons, Inc., 300 Fourth Ave., New York 10, N. Y.
Pressure transducers	2 pp.	Bulletin 58–131, 58–135, 58–140	BJ Electronics Div., Borg-Warner Corp., 3300 Newport Blvd., Santa Ana, Calif.
Metering pumps	4 pp.	Bulletin 1257-1	Milton Roy Co., 1300 E. Mermaid Lane, Philadelphia 18, Pa.
Surveying and monitoring instruments	2 pp.	Bulletin FHS 195e	Frieseke & Hoepfner, GMBH, Erlangen-Bruck, West Germany
High-temperature alloys	4 pp.	"Tidings" 3, No. 4 (1958)	Techalloy Co., Inc., Rahns, Pa.
Aluminum billet casting	8 pp.	Publication 591	Lobeck Casting Processes, Inc., 114 E. 32nd St., New York 16, N. Y.
Gamma-ray detector	1 p.	Bulletin 1918	Riggs Nucleonics Corp., 717 Victory Blvd., Burbank, Calif.
Digital computer	8 pp.	"Nuclear Reactor Monitoring"	Thompson-Ramo-Wooldridge, Inc., P. O. Box 90067, Airport Station, Los Angeles 45, Calif.
Digital computer	6 pp.	Brochure S-526R1	Royal McBee Corp., Port Chester, N. Y.
Closed-circuit TV	8 pp.	Catalog 6-103	Cohu Electronics, Inc., 5725 Kearny Villa Rd., San Diego 11, Calif.
Corrosion	2 pp.	"Chemical Engineering" reprint	Columbia-National Corp., 70 Memorial Dr., Cambridge 42, Mass.
Demineralizers	4 pp.	"Industrial Demineralizers"	Penfield Mfg. Co., Inc., 19 High School Ave., Meriden, Conn.
Scintillation counters	30 pp.	Bulletins 5–14	National Radiac, Inc., 479 Washington St., Newark 2, N. J.
Cobalt	43 pp.	"Cobalt"	Cobalt Information Center, 505 King Ave., Columbus 1, Ohio
Neutron source	4 pp.	Bulletin PN	High Voltage Eng. Corp., Burlington, Mass.
Seal joints	—	Catalog I-11	Marman Div., Aeroquip Corp. 11214 Exposition Blvd., Los Angeles, Calif.
Ceramic seals	2 pp.	Report AR/201 and List E.CMS/458	Ferranti Electric, Inc., 95 Madison Ave., Hempstead, N. Y.
Biophysical instruments	16 pp.	"Medical and Scientific Progress"	Biophysical Electronics, Inc., 400 Northern Blvd., Great Neck, N. Y.
Forgings	40 pp.	"Forging"	Cameron Iron Works, Inc., P. O. Box 1212, Houston, Tex.
Index of M-H product literature	24 pp.	Bulletin G2-1a	Minn.-Honeywell Regulator Co., Wayne & Windrim Ave., Philadelphia 44, Pa.

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INDUSTRY NOTES

• AEC has ordered 24 "Banshee" devices from **Tracerlab** for delivery by mid-July. Banshee (NU, Feb. '59, 29) is a miniaturized radiation-warning device to be attached to home or auto radio sets. The $10,000 contract ($435 per device) is one of several from both civilian and military customers which gave Tracerlab $500,000-plus in new business in the month ended May 15.

• **Salem-Brosius** has acquired 75% ownership of **General Ionics Corp.**, Pittsburgh, a water-softening and -conditioning firm which built the demineralizing equipment for the submarine *Nautilus* and other atomic facilities. General Ionics will operate as an S-B subsidiary.

• **Analab Instrument Corporation** has been formed at Cedar Grove, N. J.—30 Canfield Road—to design and manufacture analytical laboratory instruments. President Morton G. Scheraga, formerly of Allen B. Du Mont Laboratories, said first step was to assemble the team of engineers which will "develop a line of unique new products in the broad area of instrumentation."

• In a series of **uranium-industry** developments: (1) AEC announced shutdown Jan. 1, 1960, of its **Monticello, Utah, ore mill;** (2) AEC has signed a contract running through 1966 with **Globe Mining Co.**, wholly-owned subsidiary of **Union Carbide Corp.**, for delivery of U concentrates from Wyoming; Globe started construction immediately on a 492-tpd mill in Natrona County, Wyo.; and (3) **Vitro Minerals Corp.** has contracted to deliver 480,000 lb/yr U-oxide, through 1966, to The Susquehanna Corp.

EXPANSIONS. **NRC Equipment Corp.**, subsidiary of **National Research Corp.**, has established an engineering office at Palo Alto, Calif., to promote its products in the West Coast market. . . . **Alsca Beryllium Machining Corp.** has opened a plant at Valley Stream, N. Y., for precision machining of Be metal components.

DISTRIBUTION. A licensing agreement has been signed by **Thompson Ramo Wooldridge** and **Intertechnique Co.**, France, for the manufacture and sale of RW-300 computers in France; two of the computers were recently ordered by Electricite de France for its EDF-1 reactor (NU, May '59, 34). . . . **Hughes Aircraft** has signed distributor agreements with nine European firms for sale of its commercial products in all of Western Europe.

FINANCIAL. First quarter sales and earnings of **Combustion Engineering** hit historical highs at $81,094,000 and 58 cents/share, respectively. . . . **Beryllium Corp.** has declared a 3% stock divident payable June 30. . . . **Thompson Ramo Wooldridge** reported substantial gains in sales of nuclear equipment in the first quarter '59. . . . **Technical Operations** has split its common stock 3-for-2 and increased authorized shares from 450,000 to 1,000,000 to clear the way for a public sale aimed at increasing capital funds; the firm has acquired "substantially all" of **Microwave Associate's** interest in **Power Sources, Inc.**, formerly a joint subsidiary of the two companies. . . . **Victoreen Instrument** has declared a 25% stock dividend payable June 16; record sales and earnings for the first quarter were reported—sales 77% and earnings 60% ahead of first quarter '58. . . . **Tracerlab** offered 100,000 shares of its common to the public last month at $11/share; proceeds were to go for research and development (75%) and sales activities (25%). . . . **Nuclear Corp. of America** has reported a 20% increase in sales in '58 over '57, including a 30% increase in sales of its **Isotope Specialties div.** . . . . **Western Gold & Uranium** reported net earnings of $632,237 (41 cents/share) for the year ending Jan. 31, compared with a loss of $552,020 in the preceding year.

NEW BUSINESS. A contract for more than two tons enriched U-dioxide powder has been awarded **Nuclear Materials and Equipment Corp.** by Westinghouse; the powder, in pellet form, will go into fuel elements for the Belgian BR-3 reactor. . . . **Girdler Construction div. of Chemetron Corp.** has been selected architect-engineer for new research and production facilities at AEC's Mound Laboratory. . . . Apparent low bidder for construction of Sandia Corp.'s Engineering Reactor Facility (NU, Nov. '58, 25) was **Petroleum Combustion and Engineering Co.**, Los Angeles; Sandia will provide core, pressure vessel and associated controls and cooling equipment. Operation target is early '61.

NUCLEAR CAMPUS

• As of mid-May, AEC had made $330,000 available to 13 educational institutions under its program to help equip colleges and universities for **radioisotope technology training** (NU, Apr. '59, 177); another $200,000 was expected to be granted by end-June. Grants ranging from $2,755 to $80,000 have gone to Univ. of California (Berkeley), Univ. of North Carolina, Virginia, Stanford, St. Joseph's, North Georgia, West Virginia, Walla Walla, Kansas State, Louisiana State, Xavier, Purdue and Gustavus Adolphus.

• **Campus Facilities.** A 10-kw pool training reactor purchased from General Electric by **Stanford Univ.** will be in operation this fall. . . . **Florida Univ.** has given up hope of getting its 10-kw reactor into operation this spring; it must be inspected and licensed by AEC and run through a series of preliminary tests which, together, have given an indefinite status to startup. . . . Also running into delays is the **Univ. of Virginia** reactor, which has been given a one-year extension by AEC on its construction permit —to July 1, 1960. . . . **Carnegie Institute** has taken delivery of a total-absorption Cherenkov counter—a gift from GE—to be used for studying nuclei and mesons produced by Carnegie's 430-Mev synchrocyclotron.

Courses

AEC, in cooperation with the National Science Foundation, hopes to offer a study program for college faculty in **radioisotope principles and technology**—in the summer of 1960 and for 3–5 summers thereafter. AEC is offering two short radioisotope courses this summer at Oak Ridge National Laboratory: **advanced industrial research techniques** (Aug. 17–28) and **advanced industrial techniques** (Aug. 31–Sept. 11). A six-week course in **industrial isotope techniques** is scheduled Oct. 5–Nov. 15 at ORNL.

Applications from native and foreign applicants are due July 10 for two reactor courses, beginning this fall, at ORNL: **nuclear reactor operations supervision** (Nov. 2–July 20) and **nuclear reactor hazards evaluation** (Nov. 2–Oct. 29). Contact AEC's Division of International Affairs, Washington 25, D. C., if a native, or the respective embassy or legation in Washington.

Robert A. Taft Sanitary Engineering Center, Cincinnati, is offering **radionuclides in food**, Sept. 14–25.

Vitro Engineering Company regularly furnishes consulting services to those concerned with the advanced technologies of the Atomic Age. Consultation is the start of Vitro's complete engineering services, which include design, procurement, construction, start-up and operations training. Current consulting contracts include:

THE GOVERNMENT OF ITALY—under contract to AGIP Nucleare, Vitro is evaluating reactor design and cost criteria for a 180,000 KW nuclear power station.

BROOKHAVEN NATIONAL LABORATORIES — Technical and economic evaluation and engineering study of fuel processing methods for the Liquid Metal Fuel Reactor (LMFR).

WESTINGHOUSE ELECTRIC CORPORATION—Study and analysis of mechanical, thermal and hydraulic problems associated with the reactor design for the first nuclear aircraft carrier (A1W).

GOVERNMENT OF INDIA—Design engineering and consulting services for a large heavy water-ammonium nitrate fertilizer complex.

CONSOLIDATED EDISON COMPANY OF N. Y.—Indian Point Station—Consulting services for a 275,000 KW electrical generating nuclear power plant.

CORNELL UNIVERSITY—Consultation relating to dual core reactor training facility.

Other areas of consulting have included—advanced metallurgical techniques, chemical and industrial processing and radiological laboratories. Studies have included technical feasibility, conceptual design, economics, safety, security and master planning.

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NEWSMAKERS

Thomas D. Hanscome of the Naval Research Laboratory (Chesapeake Bay) and **Walter G. Wadey** of Yale Univ. have joined the Nuclear Electronics dept., Hughes Aircraft Co.

Martin Co. has named **Harry P. Kling,** a physical metallurgist, manager of the Nuclear Components dept., Nuclear div. Kling will direct all research, development and production on fuel elements, control rods and other components for reactors and isotopic power units. He spent ten years with Sylvania Electric Products and Sylvania-Corning Nuclear Corp.

Kling

A second engineer from Argonne National Laboratory has joined the Norwegian boiling-heavy-water project at Halden—**Leonard W. Fromm, Jr.,** head of the Water Reactors section of ANL's Reactor Engineering div. **James A. DeShong, Jr.,** has been consulting at Halden for more than six months.

George J. Casaletto has left his post as senior research engineer in the Rocketdyne div., North American Aviation, to join the Radiation Chemistry branch of the Chemical Technology div., Naval Radiological Defense Laboratory, San Francisco.

Bruce H. Billings, vice-president and director, Baird-Atomic, has been appointed assistant director of research and engineering (in charge of special projects) in the Department of Defense—under Herbert F. York. He has been succeeded at B-A by **George B. Foote,** treasurer of the firm since 1957. **David B. Lawrence** has joined B-A as manager of industrial relations from Itek Corp., where he was assistant to the president.

Billings

The director of H. K. Ferguson's Nuclear div., **Edward L. Heller,** is one of ten Ferguson men named to directorships or assistant directorships under a program to give the men responsibility for technical excellence of both engineering design and construction of facilities in their fields.

Alfons Puishes, a nuclear patent attorney for ten years, has left Standard Oil of California to establish private practice at 1095 Market St., San Francisco. Puishes will specialize in the nuclear field.

The Budd Co. has named **Aaron V. Kelley** general sales manager of the Nuclear Systems div.

Personnel developments affecting both the military and commercial nuclear activities of General Electric include: **John D. Selby** has been promoted from manager of power plant systems engineering, Submarine Advanced Reactor Project (SAR) to manager of the project; **Vice Admiral Willard A. Kitts,** USN (ret.), has been compulsorily retired (age 65) from his post as manager of the Atomic Products Study of the Atomic Products div.; and **Richard L. Schmidt** has been selected to fill a new post—manager, government research and development applications—in the Atomic Power Equipment dept. He will direct work under contracts with Euratom and the U. S. government and, as well, handle marine and special military applications of nuclear power.

Selby

Kitts

Robert A. Arrison has been named to fill a new post at Keleket X-Ray Corp., subsidiary of Tracerlab—vice-president for engineering. The post was created because of increased activity in low-radiation-hazard X-ray development.

In three key staff additions at Applied Radiation Corp.: **Sam A. Wenk,** engineering-test chief at Lawrence Radiation Laboratory, has taken charge of ARCO's radiographic div.; **August S. Klein,** assistant sales manager for Nuclear Science and Engineering, has been

named manager of marketing; and **Donald S. Ramseyer** has joined ARCO as vice-president and business manager.

In a major realignment of managerial personnel at both General Dynamics and two of its divisions—General Atomic and Electric Boat—the following have been promoted: (1) GD: **Frank Pace, Jr.,** president, has been elected board chairman; his successor is **Earl D. Johnson,** formerly executive vice-president; **C. Rhoades MacBride** has been named senior vice-president for operation (2) EB: **Carleton Shugg,** general manager of EB and a senior vice president of GD, has been elected president of Electric Boat; (3) GA: **Frederic de Hoffman,** general manager of GA and a vice-president of the parent firm, has been elected president of GA and a senior vice-president of GD; **E. C. Creutz** has been promoted from director of the John Jay Hopkins Laboratory to vice-president in charge of research; **H. B. Fry** was named vice president for administration; and **C. A. Rolander,** an assistant to de Hoffman for two years, has been named vice-president for program development.

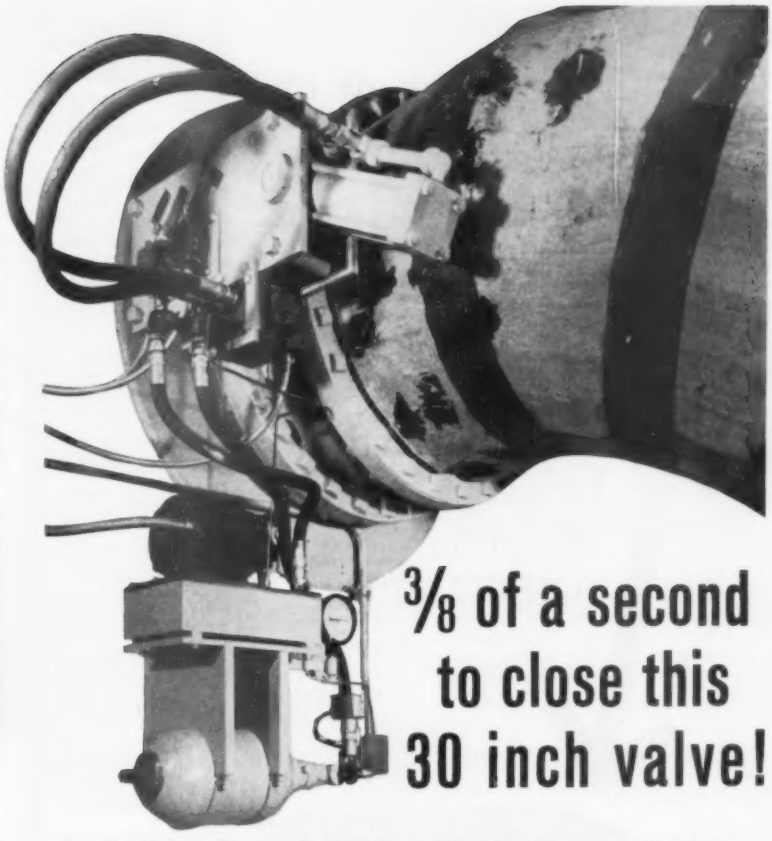
Creutz

Fry

Rolander

A 43-year-old, 15-year veteran of the nuclear energy program, **Jon D. Anderson,** has joined the New York Office of Atomic Development as deputy director to Oliver Townsend (NU, Apr. '59, 27). Anderson was manager of the AEC's Schenectady Operations for almost nine years; he first entered the field in 1944 as an officer in the Manhattan Engineer District.

Anderson



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July 13–17—Western Resources Conference, Boulder, Colo. (*Univ. of Colorado*). Several nuclear sessions. Contact Committee on Western Resources, New Chemistry Bldg., Rm. 305, Univ. of Colorado, Boulder.

July 17—9th Annual International Conference on High Energy Nuclear Physics, International Union of Pure and Applied Physics, Moscow. Contact Robert E. Marshak, Univ. of Rochester, Rochester, N. Y.

July 22–25—International Conference on Waste Disposal in the Marine Environment, Univ. of California, Berkeley. Session on radioactive wastes. Contact Dept. of Conferences, Univ. Extension, Berkeley 4, Calif.

July 23–30—9th International Congress of Radiology, Munich, Germany, sponsored by International Society of Radiology. Contact Secretariat, Reitmorstrasse 29, Munich 22.

July 28–31—International Conference on the Preservation of Foods by Ionizing Radiations (*Mass. Inst. of Technology*). Contact B. E. Proctor, MIT, Cambridge, Mass.

Aug. 17–21—4th International Conference on Ionization Phenomena in Gases, Uppsala, Sweden. Program includes high-temperature plasmas and controlled fusion. Abstracts due June 15 (350 words). Contact Ake Nilsson, Institute of Physics, Uppsala.

Aug. 20–21—Symposium on Industrial Uses of Radioisotopes, Buffalo, sponsored by Chamber of Commerce, Canisius College and Univ. of Buffalo in cooperation with AEC Office of Isotopes Development. Contact Charles F. Light, Buffalo C. of C., 238 Main St., Buffalo 2, N. Y.

Sept. 5–11—Conference on Application of Large Radiation Sources in Industry, with emphasis on chemical processing, Warsaw, Poland. Contact A. I. Galagan, IAEA, United Nations, N. Y., or IAEA, Vienna.

Sept. 14–19—International Conference on High Energy Accelerators and Instrumentation. Contact CERN Conference Secretariat, Geneva 23, Switz.

Sept. 28–Oct. 1—Ninth Annual Instrument Symposium and Research Equipment Exhibit, Bethesda, Md. (*National Institutes of Health*). Contact James B. Davis, NIH, Public Health Service, Bethesda 14.

Sept. 28–Oct. 1—National Power Conference, cosponsored by American Society of Mechanical Engineers and American Institute of Electrical Engineers, Kansas City (*Muehlebach*). Contact ASME or AIEE, 33 W. 39th St., N. Y., N. Y.

Sept. 22–24—3rd Industrial Nuclear Technology Conference on nonpower applications of nuclear technology, cosponsored by Armour Research Foundation and NUCLEONICS, Chicago (*Morrison*). Contact Leonard Reiffel, ARF, 10 W. 35th St., Chicago 16, Ill.

Oct. 6–9—International Symposium on High-Temperature Technology, Asilomar, Calif., sponsored by Stanford Research Institute. Contact Dept. 734, SRI, Menlo Park, Calif.

Oct. 15–16—Radiation Effects Symposium of Glass Div., American Ceramic Society, Galen Hall, Pa. Contact Norbert Kreidl, Bausch and Lomb Optical Co., Rochester 2, N. Y.

Oct. 26–28—Third Conference on Analytical Chemistry in Nuclear Reactor Technology, Gatlinburg, Tenn. Contact C. D. Susano, Oak Ridge National Laboratory, P. O. Box Y, Oak Ridge, Tenn. (papers), or Tom Woods, Mgr., Mountain View Hotel, Gatlinburg (accommodations).

Nov. 2–6—Joint Meeting of Atomic Industrial Forum and American Nuclear Society, Washington, D. C. (*Sheraton Park*). AIF's annual meeting scheduled first three days (Nov. 2–4), ANS' semiannual meeting begins third day (Nov. 4–6). For AIF meeting contact AIF, 260 Madison Ave., N. Y. 18, N. Y.; for ANS meeting contact ANS, John Crerar Library, 86 E. Randolph St., Chicago 1.

Nov. 4–6—National Automatic Control Conference, Dallas (*Sheraton*), sponsored by Institute of Radio Engineers. Also participating: American Institute of Electrical Engineers and Instrument Society of America. Contact G. S. Axelby, Westinghouse, Box 746, Baltimore 3, Md.

Nov. 12–13—National Industrial Research Conference, Chicago (*Sherman*), sponsored by Armour Research Foundation. Contact ARF, 10 W. 35th St., Chicago 16.

Nov. 16–21—Conference on Disposal of Radioactive Wastes, Monaco, sponsored by International Atomic Energy Agency. Contact IAEA, 11-13 Karntnerring, Vienna 1.

Dec. 1–2—Florida Workshop Conference on Industrial Isotopes, Miami, sponsored by AEC and Florida Nuclear Development Commission. Contact latter at 218 Centre Bldg., Tallahassee, Fla.

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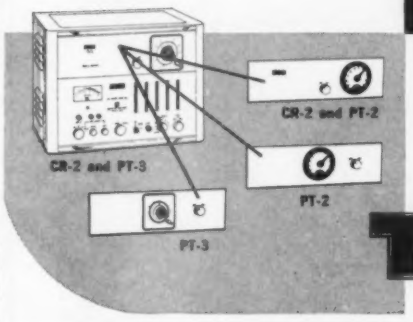

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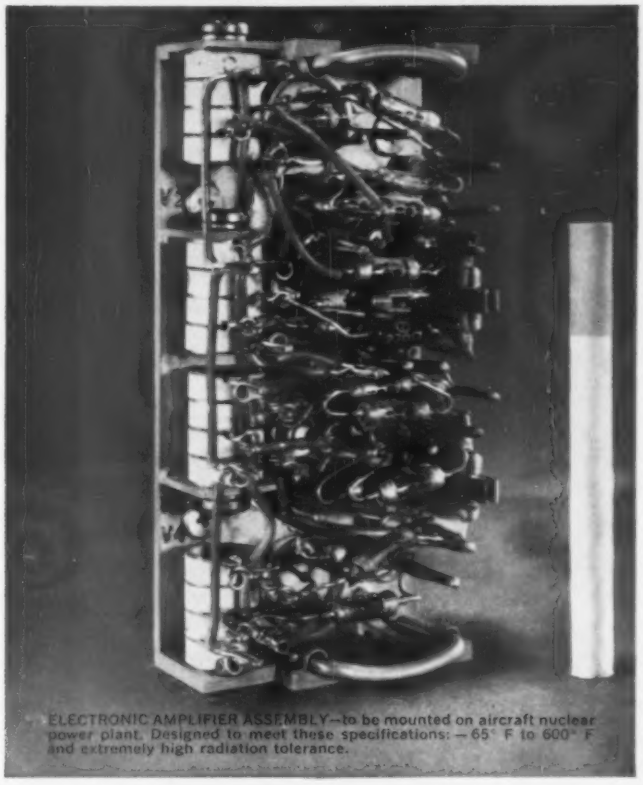

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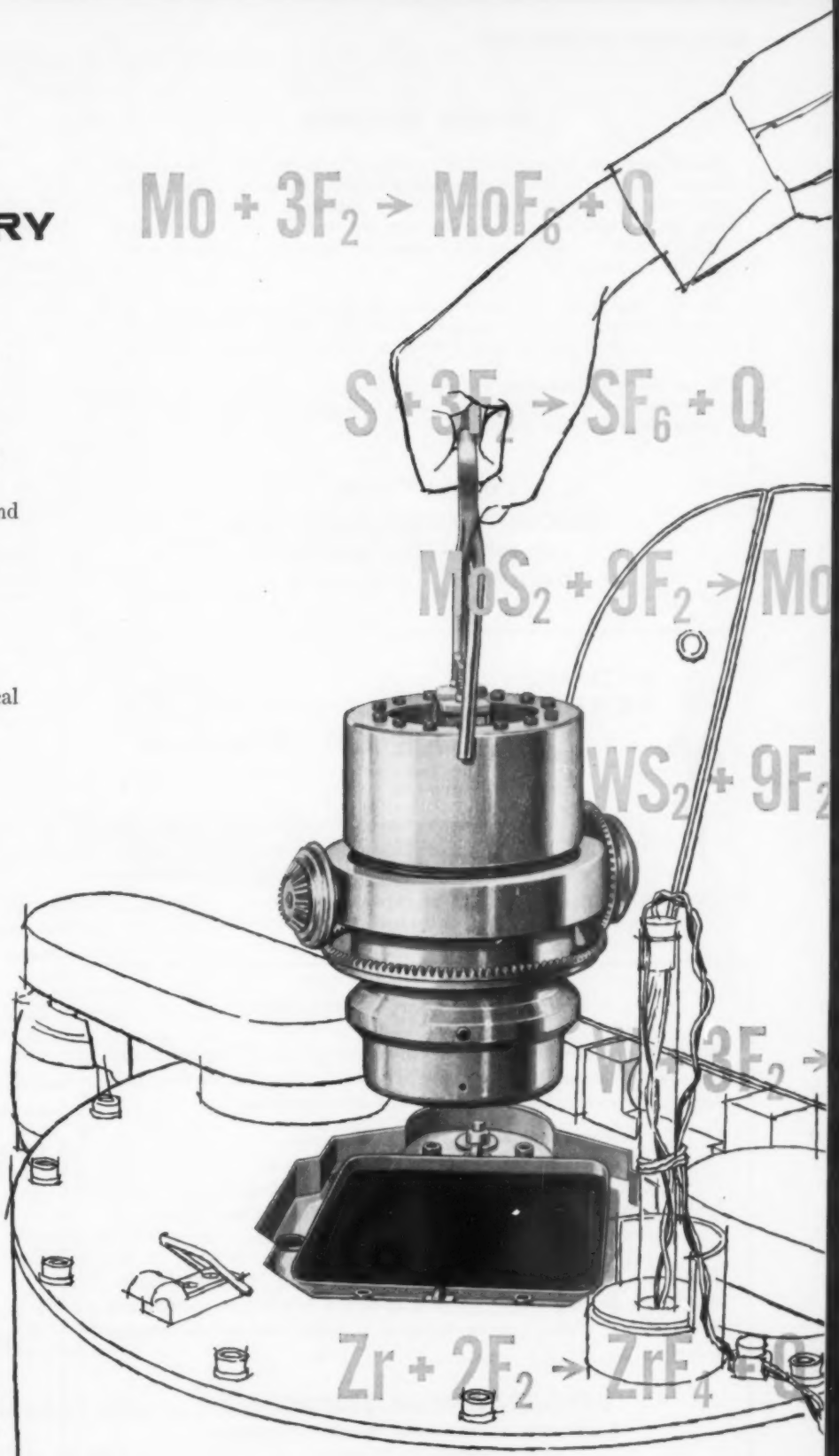

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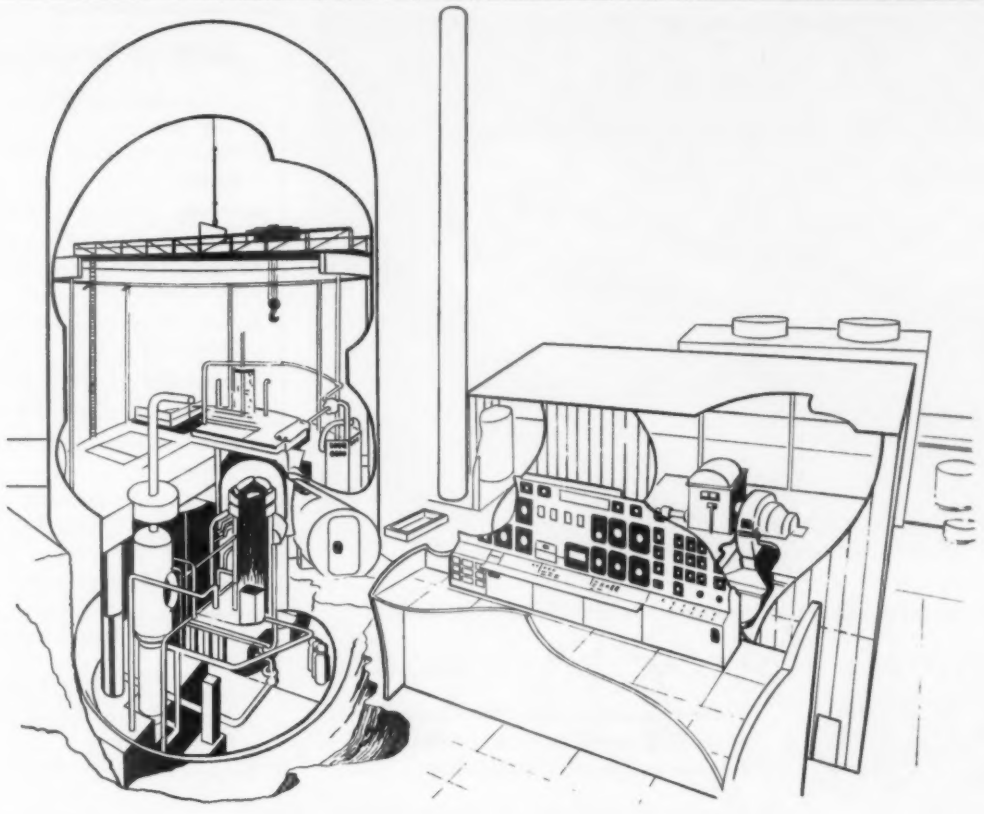

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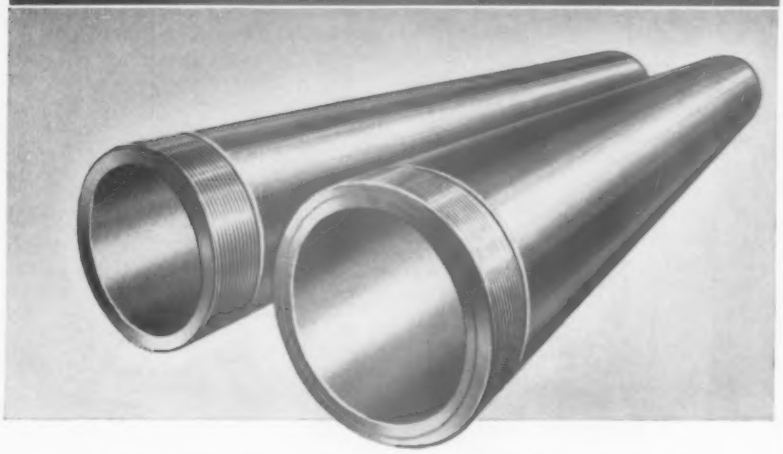

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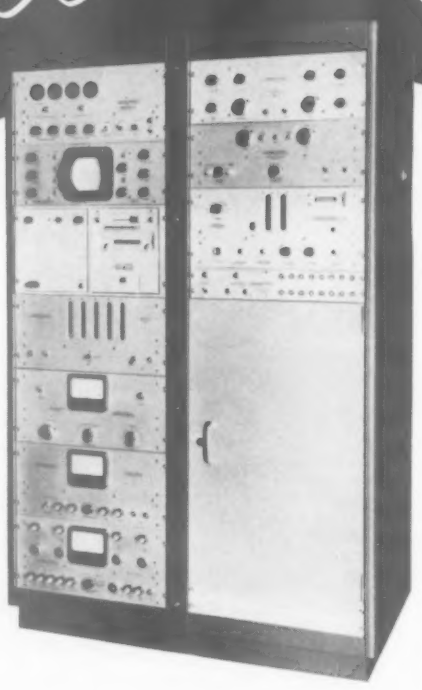

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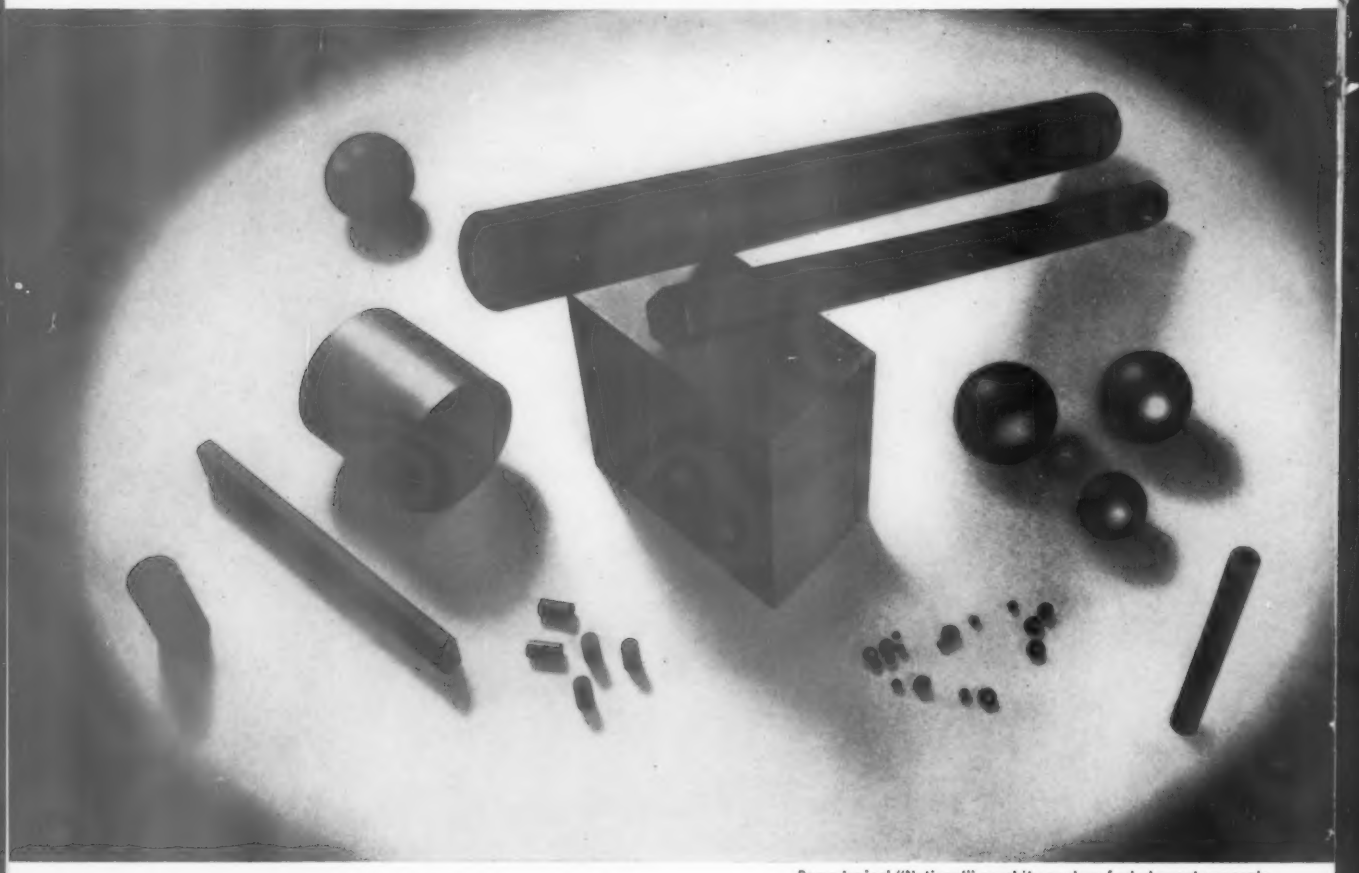

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